STUDENT-CENTERED TEACHING

IN THE

CHEMISTRY CLASSROOM

By

KERRY HAMMETT

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Thesis Approved:

Dr. John Gelder

Thesis Adviser

Dr. Nicholas Materer

Dr. Mark Rockley

Dr. Richard Bryant

Dr. A. Gordon Emslie

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Meta-cognition, epistemology, and learning have been studied for thousands of years, but reasons still exist to analyze and dissect learning methods today. Cognition theories are less accepted and less understood than other theories like evolutionary theory in biology, probability theory in math, or decision theory in economics. Why, then, have philosophers and educators been unable to take theories of cognition into the realm of the universally accepted law? Why has research, along with careful and controlled experiments, been unable to decipher a theory of learning superior to other theories? Certainly, learning has been around since the dawn of life on Earth, and many theorists have tried, but as research continues to come to conclusions, many professionals do not feel that alternative methods (methods deviating from the lecture format) of teaching are inherently better (French, 2005). For decades public education in the U.S. has been controversial (Bracey, 2006), yet there has been no discernable increase in educational achievement as a result of the ensuing efforts to improve the quality of education in the United States.

While no learning theories or methods have an impeccable record of success, empirical research is still the most logical system available for determination of the teaching methods that have the highest probability of effectiveness. The higher the probability of effective learning, the closer the U.S. is to its ambitions: to provide a free and appropriate public education for all citizens and to remain the most powerful nation, both economically and militarily.

Assumptions and Purpose

This paper assumes that public science education in the U.S. is below the level it could be at, and that a lack of effective instructional techniques is a major factor affecting the substandard scholarship in this area. It is also assumed that besides parents and socio-economic status, the classroom teacher is the most influential variable in a students' education (Moore, 2000), and therefore, teachers are the key to educational reform in the U.S. Further, it is assumed that there are three general intellectual styles (type I for people who tend to think creatively and resourcefully, type II for people who are more skilled at memorization, and type III for people who use different styles [type I and II] depending on the situation) and that the current U.S. educational paradigm rewards type II students while employers in the economic industry value people with a type I intellectual style (Zhang & Sternberg, 2006). Last, it is assumed that this inconsistency has limited economic progress in the U.S. and that a paradigm shift in public education will help to alleviate the problem.

Science is one area of education that has been determined to be inadequate but necessary for success in the global, technology-based economy, and it has been reported that the number of U.S. students pursuing science-related fields after high school is on the decline (George, 2006; Heylin, 2004). This paper will focus on methods of science education for several reasons. Besides the increasing demand of scientific type I intellectuals with mathematical and problem-solving skills for industry and innovation, science education is important because it incorporates all of the core subjects simultaneously. Math is used in context rather than for the sake of merely applying an algorithm, reading comprehension is advanced through the practice of reading and understanding complex and abstract concepts, and writing is used as the students communicate their scientific understanding. Additionally, it is assumed that the scientific method is the epitome of logical thinking, reasoning, and problem-solving skills. Practicing the scientific method gives students a starting point from which to launch all of their academic and professional endeavors.

After a synopsis of the current state of education in the U.S. and abroad, this paper will examine and compare research and theories in cognition, learning, and education. A curriculum for a general chemistry class that reflects current research of student-centered pedagogy will be developed, applied to students, and used for further understanding of alternative styles of instruction. Analysis of the use of the curriculum will answer several questions:

1. Are student-centered teaching methods effective for teaching abstract concepts?
2. What scientific concepts are particularly suited for student-centered teaching methods?
3. Can a minimally experienced teacher (Crawford, 1999) lead a student-centered classroom?
4. What are the challenges of leading a student-centered class?

5. What student characteristics correspond with success in a student-centered class? Does a student-centered class differentiate between students with type I and type II intellectual styles?

6. What are students' views of a student-centered class?

It is hoped that through stringent adherence to scientifically tested methods, the format of the class can serve as an example for the kind of restoration needed in the Unites States school system. Problems found in the current education system will be juxtaposed with theories of learning and current psychological and educational research in order to find appropriate and practical solutions. The author will evaluate the realistic application of the solutions by incorporating the solutions in a college-level general chemistry class and attempt to answer the above-mentioned questions in the process.

Educational Research

Educational research generally falls into one of two categories: descriptive research or experimental research. The main difference between the two types of research is the degree of control over the variables. In descriptive research, information is acquired relating to some phenomena in order to explain the relationship that exists between a variable(s) and the phenomena, for example, a correlation. In experimental research, all variables that may affect the result are controlled or randomized so that a researcher can more conclusively predict results (Key, 1997). Educational research tends to fall into the descriptive research realm because of the wide number of variables that can affect a student's learning.

Action research is a kind of descriptive research that is defined by educational researcher Stephen Kemmis in Hopkins' (1983) guide to educational research.

> Action research is a form of self-reflective enquiry undertaken by participants in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations in which the practices are carried out. It is most rationally empowering when undertaken by participants collaboratively, though it is often undertaken by individuals, and sometimes in cooperation with "outsiders." In education, action research has been employed in school-based curriculum development, professional development, school improvement programs, and systems planning and policy development.

John Elliot (1991) also has a useful description of action research; "It aims to feed practical judgment in concrete situations, and the validity of the 'theories' or hypotheses it generates depends not so much on 'scientific tests' of truth, as on their usefulness in helping people to act more intelligently and skillfully."

The research methods used for this project were largely descriptive and action-based, and solely concentrated on the subject of chemistry. Specifically, "chemical education research is the systematic investigation of learning grounded in a theoretical foundation that focuses on understanding and improving learning of chemistry" (Herron & Nurrenbern, 1999). The main goal of this project was to collect qualitative information rather than quantitative information; however, quantitative information and statistical analysis will be used to substantiate the presence of correlations between specific variables. The results of the research were generalized for late high school- to college-level chemistry students with little to no experience with chemistry. Despite the small sample size (n=13), statistically significant correlations were found, but because of the small sample size, research on much larger populations of students must be performed in order to make any firm and widespread generalizations.

The Current Status of Education in the U.S.

It is both legally and widely accepted in the United States that all children have the right to an education (Universal Declaration of Human Rights, 1948; Steelman, 1998; Bybee, 2007). However, the notion that education is severely lacking in the United States is also a widely held belief (Lemke, 2007), and there are many possible causes for the real or apparent educational crisis in the U.S. Theories for possible causes for the crisis include overcrowded schools, understaffed schools, lack of teacher accountability, lack of time, lack of homework, lack of funding, lack of teacher preparation, lack of student interest, lack of technology, social problems, and every possible combination of the aforementioned causes (Baines, 2007; Buchen, 2003; Lemke, 2007; Fischman, DiBara, & Gardner, 2006).

Politicians, at times, seem to want results but are unconcerned about the means. Examples of this can be seen in the history of educational policy in the U.S., particularly during and after World War II, when victory and power were seen as a direct result of knowledge and innovation. On several occasions, when the U.S. has been threatened by other countries or has been in a social crisis, the political answer has been legislation passed in an effort to strengthen education—almost to the point that public education has been treated as a scapegoat for the country's problems (Bracey, 2007).

When the Soviet Union launched Sputnik in 1957, the U.S. went into a worried frenzy (Bracey, 2007). In 1958, the U.S. congress passed the National Defense Education Act (NDEA), which aided both public and private education in the U.S. by providing low-interest loans for college students and money for improvement and change at the elementary and secondary levels (Powell, 2002). The NDEA put emphasis on the advancement of science and mathematics education, as well as foreign language.

The next major federal education legislation came in 1965 as the Elementary and Secondary Education Act (ESEA). Under Title 1 of this act, federal funds are distributed to schools as a function of the percent of students at or below the poverty level (Powell, 2002). The act also stipulates that schools that receive federal aid under Title 1 be under federal regulation. ESEA has been reinstated every five years since 1965.

The competence of U.S. public schools was questioned again in the early 1980s amidst an economic recession. In 1983, a congressional committee published *A Nation at Risk*, a litany of educational statistics implicating the educational system in America for the recession (NCEE, 1983). This document warned that if the United States did not improve public education, the U.S. would lose its economic standing in the world. The report cited that national science achievement scores decreased between 1969 and 1973 and between 1973 and 1977, that SAT scores steadily declined between 1963 and 1980, and that the average achievement of high school students on most standardized tests had decreased over the last 25 years (Bracey, 2003). While the U.S. economy has had ups and downs over the last 25 years, some educators and economists feel that *A Nation at Risk* predicted the economic trends of today; for instance, unskilled and low-skilled jobs have been increasingly out-sourced to other countries (Lee, 2007), and the income gap between the "rich" and the "poor" has steadily increased over the last two decades (Knapp, 2000). Then again, although education has not changed dramatically in the last 25 years since *A Nation at Risk,* when Bracey (2003) compared 35 countries international test scores from 2001 with their global competitive ranking as reported by the World Economic Forum (WEF) in 2001, he found that the United States was ranked first in global competitiveness among the 35 nations and that the correlation between test score and global competitiveness ranking was a mere .19. This finding negates the proposition that global competitiveness is directly related to standardized test scores.

Still, the federal government pressed on in an effort to coerce students and schools to achieving higher standardized test results. In 1994, the Clinton administration's reauthorization of ESEA was called the Improving America's Schools Act (IASA), which provided for more funding for Title 1 schools and accountability, and also provided for charter schools (publicly funded schools that are not held to the same rules and regulations of public schools, yet have stricter accountability for student performance). Also in 1994, the U.S. legislature passed *Goals 2000: Educate America Act* (H.R. 1804, 1994). The fifth goal was that "[b]y the year 2000, United States will be first in the world in mathematics and science achievement" (Goals 2000: Educate America Act, 1994; Sec. 102). In 2008, this is not the case.

Current policy makers still describe the public school situation in the United States as direly inadequate. President Bush declared, “We must address the low standing of American test scores among industrialized nations in math and science, the very subjects most likely to affect our future competitiveness,” when announcing his first education bill to be sent to Congress in 2001. In 2000 a television commercial, Bush said, “Seven out of 10 fourth graders in our highest poverty schools cannot read a simple children’s book. Millions are trapped in schools where violence is common and learning is rare” (“On the Issues,” n.d.). Hillary Clinton said, “I really believe that it takes a village to raise a child--and the American village has failed our children.” Senator Barack Obama thinks the current public school status quo is “indefensible” (“On the Issues,” n.d.). The politicians do have a valid point; it has been reported that one million students fail to graduate every year (Toner, 2007). These political and media statements about education only increase the fear of economic recession in the United States which gained prominence in late 2007 and early 2008 amidst high oil prices, a faltering real estate market, a slowdown in job creation, and a weak dollar (Goodman, 2008).

Educational Indicators

Education has become more and more of a political issue because of its potential effect on the economy. Some of the most alarming sources of educational concern have stemmed from several international studies. The Trends in International Mathematics and Science Study (TIMSS) -- which has been conducted in 1995, 1999, 2003, and 2007-- is the most widespread international education study. Students from 50 countries have participated in these studies, funded by the International Association for the Evaluation of

Educational Achievement (IEA) and within the U.S. by the National Science Foundation (NSF) and the National Center for Education Statistics (NCES) (Bybee, 2007). This study is monumental in that it not only tests and compares students, but also investigates textbooks used, curriculum, instructional methods, and student interest and motivation (U.S. National Research Center TIMSS n.d.; Bybee, 2007). The Program for International Student Assessment (PISA) has conducted achievement tests in 2000, 2003, and 2006. PISA measures 15-year-olds' reading literacy, mathematics literacy, and science literacy, and is funded by the Organization for Economic Cooperation and Development (OECD).

At the national level, the United States publishes National Assessment of Educational Progress (NAEP) "report cards" every year in order to assess the public education system. The NAEP measures a sample of fourth-, eighth-, and twelfth-grade students' abilities in reading, mathematics, and science. Fourth- and eighth-grade students are tested every two years and twelfth-grade students are tested every 4 or 5 years (NCES, n.d.). Other national educational statistics can be gathered from college entrance exams such as the ACT and the SAT.

Third International Mathematics and Science Study

TIMSS is administered in a four-year cycle to around 50 countries and over 500,000 students (Harmston & Pliska, 2001). The study aims to compare the student achievement to curriculum in order to determine the efficacy of teaching practices in nations around the world (NCES, n.d.). Overall, the U.S. tends to perform around the average level of all countries participating in TIMSS studies (Bybee, 2007). TIMSS scores indicate that fourth-grade students' science scores have not increased between 1995 and 2003. Eighth-grade students showed no increase in average score between 1995 and 1999; a slight increase was reported between 1999 and 2003. However, in 2003, U.S. fourth-, and eighth-grade students' average scores were above the international average in mathematics and science (NCES, n.d.). In 1999, at the eighth grade level, 17 countries outperformed the U.S. in science, and 18 countries out performed the U.S. in mathematics. Countries that tend to score better in both fields include Singapore, Taiwan, Japan, Korea, Australia, Netherlands, Hungary, China, Belgium, Czech Republic, Slovak Republic, Canada, Slovenia, Russian Federation, and Finland (NCES(b), n.d.). The results from the 2007 TIMSS will be released in December of 2008 (TIMSS, 2008).

The TIMSS also reports additional information concerning how education differs by country. The United States spends the most money per student at all levels (primary, secondary, and higher) among the G-8 countries (France, Germany, Italy, Japan, United Kingdom, Canada, Russia, and the U.S.). The U.S. also requires students to attend more hours in school than most other countries. Finnish students typically attend 600 hours of school per year whereas students in the U.S. typically spend 1,100 hours in school (Baines, 2007). Japan has consistently scored high on the TIMSS, and videotape recordings collected by the TIMSS revealed some specific tactics used in science classrooms in Japan. These tactics included connecting science curriculum to students' interest and experiences, students' conducting classroom experiments, and students' sharing and discussing experimental results (House, 2006).

Program for International Student Assessment

PISA is administered triennially and aims to evaluate students' ability to transfer their education into real-world situations (PISA, 2007; Bybee, 2007). In this way, PISA is designed to measure the overall yield of education by the age of 15 (NCES, n.d.). Scores on the PISA assessment range between the low 300s to the upper 500s. The U.S. tends to score below the OECD average on PISA assessments, and in 2006, was 15 points below the OECD average in science achievement (PISA, 2007). In 2006, PISA specifically focused on science and students' ability to use scientific knowledge and reasoning in the context of everyday life. Finland was ranked number one, with Hong Kong (China) and Canada in second and third place (OECD, 2007).

PISA also gathers school demography and other social statistics via questionnaire. Some interesting conclusions from the 2006 PISA study as reported in the OECD executive summary follow. Schools that segregate students based on ability generally score lower (by 4.5 points, all other variables being equal) on PISA assessments. In 21 countries, privately educated students were higher achievers than publicly educated students. In four countries, public schooling outperformed private schooling. However, after correcting for the fact that students who attend private schools generally have a higher socio-economic status, public schools were found to generally outperform private schools by 12 points (all other variables being equal). School autonomy is not statistically correlated with above average PISA scores, but countries that tend to give local schools autonomy do achieve higher in science. Schools that make student performance publicly available scored an average of 3.5 points higher than those who do not (all other variables being equal).

Comparison of International Assessments

PISA assessments are fundamentally different from TIMSS assessments; while TIMSS assessments focus on the relationship between curriculum and achievement, PISA questions focus on transferring knowledge of subjects to real-world contexts. The goal of PISA is to be an accurate representation of a country's ability to perform in the real-world economic environment, not a country's ability to have students remember what they have learned in school (Bybee, 2007). The TIMSS concludes that U.S. fourth- and eighth-graders score above the international average of all participating nations in both mathematics and science, while PISA has shown that U.S. fifteen-year-olds score below the international average in mathematical literacy and science literacy (NCES, n.d.). This suggests that U.S. students are more proficient at answering questions relating to topics that were covered in school and less able to transfer that knowledge to practical situations.

The National Report Card

The National Assessment of Educational Progress (NAEP) was founded in 1969 by the National Center for Education Statistics (NCES) to measure education and learning in the United States. The NAEP is commonly referred to as the National Report Card for purposes of informing the public of these measurements. Periodically, the NCES administers tests in reading, mathematics, science, writing, history, and geography to fourth-, eighth-, and twelfth-graders to assess students' ability to "apply knowledge and skills in problem solving situations." Knowledge and skill measured by the tests are rated as below basic, basic, proficient, and advanced. Between 1996 and 2005, fourth-graders' science achievement has improved, eighth-graders' science achievement has not changed, and twelfth-graders' science achievement has declined ("The Nation's Report Card, 2005").

The National Report Card also collects information according to race, demographics, socio-economic status, and parent education level. Interestingly, 45% of Asian/Pacific Islander students took biology, chemistry, and physics, while 31% of white students, 25% of Hispanic students, and 22% of black students took all three classes in high school. Not surprisingly, students who took three science classes had higher science scores than students who took only two, and students who took two science classes scored higher than students who took one science course (usually biology). This suggests that one of the reasons Asian/Pacific Islander students and white students perform, on average, better than Hispanic and black students is that a higher percentage of the Asian/Pacific Islander and white students opt to take more science courses. It follows that if students were more interested in science, they would be more motivated to take the courses and more likely to score at or above proficiency levels in science. Overall, of twelfth-graders, only 54% scored at or above a basic level of science; therefore, 46% of twelfth grade students typically graduate from high school with a below-basic understanding of science ("The Nation's Report Card," 2005).

ACT and SAT College Entrance Exams

Of all students taking the American College Test (ACT) in 2007, only 28% were deemed ready to take college-level science courses (score above 19 on a scale of 1-36), and this percentage is much lower for minority groups. Students are most likely to not be ready for college-level science. To compare the readiness percentage for science with the readiness percentages of the other three subjects tested by the ACT, 69% of students are projected to be ready for college English, 43% for mathematics, and 53% for reading (ACT, 2007). Generally, American high schools require students to take four units of English and three units each of science, math, and history/government. The importance of English in high school requirements can be seen in the analysis of national ACT scores. American high schools are failing to prepare students for success in college; perhaps the relatively high rates of readiness for English and reading are achieved at the expense of math and science. Although all subjects are worthy of time and effort, science and mathematics must not be placed under English in importance if the goal of the U.S. is to be the most technologically advanced nation. The average score for the science reasoning section of the ACT score has increased by .95% between 2003 and 2007, and composite ACT scores have increased by 1.9% in the same time period, but this increase was achieved primarily by the Caucasian and Asian American/Pacific Islander groups.

Between 1963 and 1980, the average SAT score in the United States has declined considerably (Harmston & Pliska, 2001). The SAT does not contain a science portion, yet is accepted by nearly all accredited institutions of higher education (College Board, 2007). This condition silently agrees with the notion that science is a secondary subject and is not a necessary predictor of educational attainment. The purpose of the SAT is to determine a student's college aptitude, and this aptitude profile may not be complete without a scientific thinking section. As high schools and colleges strive to prepare students for their future work, science must be of central importance; of the 30 fastest growing jobs in the U.S. for the year 2008-2009, 27 are computer or health-related, which both require a firm foundation in science (United States Department of Labor, 2007).

No Child Left Behind

Although the word <u>education</u> is not mentioned in the U.S. Constitution (National Archives, n.d.) and the origins and early success of the public school systems in the U.S. occurred with a decentralization of power, the federal government has been using its legislative power in an attempt to boost the effectiveness of public schools. The most recent major legislation, the No Child Left Behind (NCLB) Act of 2001, is the latest renewal of the ESEA, first passed in 1965. The goals of NCLB are to provide accountability for schools and to decrease the achievement gap between majority and minority students. The means of achieving these goals include the following strategies: compulsory standardized testing, punishment of sub-par schools, and more funding.

The No Child Left Behind Act gives the federal government an unprecedented amount of power over state educational systems. Ironically, Secretary of Education and one of the biggest proponents of the NCLB Act, Margaret Spellings, was quoted in a *Washington Post* article in 2007 saying, "Neighborhood schools deserve neighborhood leadership, not dictates from bureaucrats thousands of miles away" ("They Said What," 2007). According to the Center on Educational Policy and the National Education Association, in response the NCLB Act, 44% of schools districts have decreased the amount of time spent on science, social studies, art, music, physical education, lunch, or recess since 2001 (“NEAtoday,” 2007).

NCLB requires educators to test progress frequently and use teaching methods based on educational research (U.S. Department of Education, n.d.). Yet most teachers still rely on the lecture-based and worksheet method of teaching (Wolk, 2007). This suggests that teachers are not prepared for their roles as teachers using methods described by current research. Wayne Au (2007) conducted a review of 49 qualitative studies focused on the effect of high-stakes testing on curriculum and teaching methods. He found that teachers are most likely to respond to high-stakes testing by narrowing content matter and becoming increasingly dependent on lecture-based, teacher-centered methodologies. However, in some cases high-stakes testing influenced teachers to include more student-centered activities and increase the amount of curriculum covered, although this result was uncommon. When the result of high-stakes testing is “teaching to the test” rather than teaching sound academic skills, the intended purpose of the high-stakes test and its diagnostic value are undermined (RAND, 2005).

Educators have found the governmental and administrative approach to be out of sync with the reality of classroom education (Knights, 2004). The government has passed legislation making public schools accountable for the success of their students (the end), but has not given appropriate consideration to the methods (the means). Often, schools have succumbed to the pressure to implement standards without regard for the teacher support and curriculum necessary to meet the standards. In order to increase academic achievement and close the achievement gap, the first step was to test students; secondly, teachers were given training; and finally, resources were spent on up-to-date curriculum

("Where we stand: Standard-Based Assessment and Accountability," 2003). The American Federation of Teachers notes that one major reason that 20-30% of new teachers quit within three years is the lack of support they receive to meet local, state, and national standards (Teacher Recruitment and Retention, n.d.). This turnover rate is too high and poses a threat to the educational goals of the U.S.

In the U.S., where states have primary control over the educational requirements, science education can differ drastically from state to state. Yet in accordance with the NCLB Act, states must report their standardized test scores for state-to-state comparison, even though the curriculum and the tests are not standardized. Although the strength of the U.S. educational system was once attributed to its decentralized organization, if test scores from various states are to be compared, then students must be taught the same concepts. If states are to have complete control over education criteria, then test scores should not be compared.

Perhaps the most detrimental effect that NCLB has inadvertently caused is a lowering of educational standards. With so much federal pressure for schools to create "proficient" students, and no specific definition of the word "proficient," the term is used variably by different states. The higher a state's standards, the smaller the number of proficient students: the lower a state's standards, the larger the number of proficient students (Bracey, 2007). The combination of neighborhood leadership that Secretary Spellings refers to with national penalties creates a system in which schools will not be rewarded for increasing standards. The NCLB system is unintentionally selective for schools with lower standards, and this discrepancy will ultimately affect the quality of education in the United States.

The Teaching Profession

Teaching, the career that has the most influence over public student education in the U.S., is suffering from a decrease in teacher specialization, a decrease in morale, and a decrease in retention rates (“High teacher turnover rates”, 2007). These problems intensify the previously named educational problems in the U.S., and stigmatize the profession of teaching. With fewer college students choosing to major in education, the educational status of the United States is sure to fall below the status quo. If more teachers were available for public school students, teachers could specialize in areas of interest to them which would be one method of increasing moral and retention rates.

Educators must understand the purpose for the content and processes they are teaching in order to clearly define learning goals and outcomes for students. Unfortunately, many high school teachers are placed in a position outside their realm of expertise, and this is especially true in the fields of science and math. To add more confusion to what is expected of high school teachers, there are both national and state standards as well as many publications that use the education verbiage like “inquiry,” “problem-based learning,” “constructivism,” and “student-centered learning” when describing different situations or contexts (French, 2005).

While the No Child Left Behind Act states that every K-12 classroom must have a highly qualified teacher by the end of the 2005-2006 school year, this plan has not been realized due to an insufficient supply of qualified teachers. In attempts to garner enough teachers necessary for the number of students in the U.S. public school system, the hiring process has become less stringent. Most states allow individuals with any degree to obtain a temporary teaching license provided they have not been convicted of a felony.

This policy cheapens the institution of teaching and challenges the reasoning behind accredited teacher training programs.

Annually, teacher turnover costs U.S. schools over 7.3 billion dollars according to the National Commission on Teaching and America's Future ("High teacher turnover rates", 2007). This deficit in teachers has led to alternative methods for degree-holding individuals to become certified to teach in public schools. As the need for teachers increases, the ability of a school district to be selective when hiring educators decreases. Several studies have called into question the fast-track teacher recruitment programs. In 2000, Wenglenski (2000) analyzed NAEP data and found that math and science teachers with a degree in the subject they teach are more likely to have their students attain subject proficiency, even when controlling for other factors such as class size, demography, and professional development.

Besides parents, teachers are often regarded as the single most important facet of a student's education (McCarthy, 1972). The learning process happens in the classroom, facilitated by the teacher, and is removed from the educational hierarchy of principals, superintendents, state superintendents, and national policy makers. Thus, instead of comparing the U.S. national educational policy with those of other countries, it is instructive to compare U.S. teacher standards and work conditions to other nations, particularly those nations that score higher on international tests like the TIMSS. It has been shown that teachers in the United States work longer hours and teach more classes than teachers in other industrialized nations. Teachers in the U.S., Britain, and the Netherlands reported having the largest teaching loads per semester, an average of five classes per day, five days a week. In Japan and other European countries, teachers have more time during the day for class preparation. Another noticeable difference is observed in the amount of education required for teachers at the secondary level. It is not uncommon in Europe to require that teachers have five or six years of college in preparation for teaching, whereas teachers in the U.S. are required to complete a four-year degree (Nelson, 1993).

Conclusion

Evidence from standardized test scores, high school graduation rates, and estimates of preparedness for college shows that the current educational system is not effective at producing adequately educated students. A decrease in the numbers of students pursuing science and science-related fields after high school adds to these concerns (George, 2006). The *Digest of Educational Statistics: 2005* reported a 30% decrease in students earning bachelor's degrees in chemistry between 1981 and 2004 and a 19% decrease in the number of bachelor's degrees in physics between the same years (2005). As a percentage of total degrees awarded, the percent of U.S. students graduating with degrees in science, mathematics, or engineering is the lowest of the G-8 countries (Miller, Malley, Owen, 2007). This is alarming to U.S. political leaders, as history details the link between scientific innovation and international power, defense, and health. American surgeon John Gibbon invented the equipment necessary for open heart surgery and performed the first successful open-heart surgery in 1953 (Singh, Dhaliwal, Lurhra, Das, & Mehta, 2006). Apollo 11 was the first manned craft to land on the moon in 1969 (The Apollo Program, n.d.). American Bernard Oliver invented pulse code modulation, which allowed information to be translated into binary code, an instrumental step leading to the digital information age (Invent Now, n.d.). Americans Ivan Getting and Bradford

Parkinson were the minds behind the global position system GPS ("GPS inventor," 2004). The Allies won World War II (or perhaps won it sooner) because of the availability of top-tier scientists. Truly, scientific innovation shaped the past and will shape the future, and the power to shape the future is held by scientists and engineers.

The founders of the U.S. viewed education as necessary for the achievement of social goals in a way that was uncommon in other western nations. This American belief led to an unprecedented percentage of society having access to an education and led to an advantage against countries where education was only for the wealthy and the pious. As a result of the power of scientific knowledge, claims of international mediocrity have been a national issue of concern since the end of World War II. Still, the correct course of action is not clear, and other countries are overtaking the U.S. while America debates and ultimately resists educational progress.

One major limitation of the argument that the U.S.'s economy and power are currently at stake is the assumption that test scores and enrollment statistics are equivalent to economic and military success, and this is a logical fallacy that appeals to fear. The studies that conclude that the U.S. is not performing well nationally or internationally are based on students' performance on standardized testing. Depending how one views intelligence, mediocre scores on standardized tests could simply mean that students do not know the answers to the questions but would be capable of learning the answer to the question, or that students lack the intelligence, problem-solving skills, or motivation necessary to answer the question. The latter view of intelligence and standardized tests does warrant alarm, but there are measures other than standardized tests that indicate the level of the U.S. global competitiveness. For instance, Asian nations, Singapore especially, typically score among the top nations in international standardized test, but envy the assumed creative nature of Americans and are ardently working to increase creative thinking at al levels of education (Bracey, 2007; Ward, 2007). Recognizing the deficit in creative thinking, Singapore Management University students are required to take a course in creative thinking in an attempt to "undo the damage of 12 years of schooling" via rote memorization (Overland, 2007). This difference in perspective is controversial among educators, and the ramifications of which side is right and which side is wrong may or may not have significant effects on the economic and military future of the United States. Perhaps there is no need for alarm, but to better science education in the U.S. would have positive ramifications for the U.S. either way.

CHAPTER II

THEORETICAL FRAMEWORK

Theories on the subjects of learning, education, and intelligence are prevalent, but no one theory has been accepted as the gold standard in education. A conglomeration of learning theories, intelligence theories, and theories of creativity and motivation provide the framework of the current study. It is hoped that by blending several theories, the overlapping facets of the theories may be amplified while the shortcomings are attenuated. The most notable theories of learning include behaviorism, constructivism, educational progressivism, and the cognitive load theory (CLT) of learning. These theories have different views, but also overlap in many ways.

Learning Theories

Behaviorism

Behaviorism presents a theory of behavior as a direct consequence of environmental stimuli. While an oversimplified view of behaviorism seems to suggest that human behavior and intelligence is animalistic, the theory has evolved to take a more complex view of behavior by incorporating human cognition. For instance, B.F. Skinner proposed that other motivations aside from one stimulus determine behavior (Skinner, 1982). Instead of just one stimulus as motivation for behavior, Skinner included other factors affecting behavior such as religion and what other people will think (Skinner, 1982). The general stimulus-response model and the reward-punishment model of human behavior does not account for the spontaneity and creativity of human behavior, so it must be regarded as incomplete (Sullo, 2007).

Educationally, the behaviorist view describes learning as a change in one's behavior that reflects what one has learned. Behaviorist research has concluded that transfer of knowledge to new situations is rare and should not be expected. As a result of this conclusion, behaviorists argue that the most efficient and reliable method of changing one's behavior to reflect learning is to directly give students all information they should be responsible for learning and test the behavioral outcome (Travers, 1978). Intelligence tests, standardized tests, and other strictly quantitative measures of knowledge are fundamentally based on behaviorist ideology: knowledge is strictly related to the behavior exhibited by the results of the test.

Pedagogically, the behaviorist view of learning is based on the acquisition of skill (Greeno, 1998). Learning in a behaviorist environment occurs when by practicing skills, students are able to perform those skills in an efficient manner (perhaps on a test). In a chemistry classroom, fundamental knowledge (of the conventions in the field of chemistry) that must be understood in order to grasp chemical concepts may best be learned by behaviorist techniques, such as repetitive drill. A behaviorist assessment, such as a traditional test of knowledge, can also be appropriate for quickly determining the extent to which students are engaged in the class.

Constructivism

The constructivist theory and the behaviorist theory take opposite approaches to learning, and the concept of constructivism is more complex in nature. The term constructivism is used when addressing either a view of knowledge or the practice of knowledge transmission (Colliver, 2002). Thus, constructivism is a theory of how the brain constructs knowledge, and the theory has been applied as a theory of learning and teaching. Constructivism views knowledge as a purely human creation that is conjured in order to make successful predictions of phenomena, to solve problems, and to organize thoughts (This is opposed to realism in which knowledge exists as a fundamental entity). (Cacioppo et al., 2004). When all knowledge is a human construction, it must be emphasized that although observations may support an idea, the idea is not necessarily true and could be subject to change. Despite the popularity of the theory as the basis for teaching and learning, the principle view of constructed knowledge is not practiced in most educational settings (Llewellyn, 2005); knowledge is inadvertently presented by instructors with a realist approach ("This is just the way things are, so accept it.") rather than as a culmination of many individuals' careful observations that have withstood the scrutiny of many other people over time.

Many learning techniques are advertised to be based on the constructivist model, for instance, student-team learning (STL) and problem-based learning (PBL). Constructivism is also the basis for designing curriculum that continuously builds on what has already been learned, to provide a foundation for new knowledge to be associated with previously learned material (Kearsley, 2007a). The scientific method, authentic science, and thus authentic science curriculum are all based on constructivism. Since knowledge is a human construction under this theory, physical observations must be made in order to make meaningful conclusions.

Progressivism

Educational progressivism posits that optimum human learning occurs when students are engaged in real-life activities with other people. This theory takes tenets from both behaviorism and constructivism. The suggestion that learning behavior should occur in real-life situations can be perceived from a behaviorist point of view. Students will ultimately have use for knowledge in real life, so knowledge should be learned in real-life situations in order for students to be able to use knowledge in real life -- since behaviorists believe transfer of knowledge to new circumstances is uncommon. Conversely, progressive education seems to be rooted in constructivism because outside the artificial learning environment of the classroom, in real life, learners must construct their own knowledge rather than listen to planned lectures. Progressive education has been touted by John Dewey, and his followers. Dewey was the first major advocate of learning by doing (Dewey, 1938). Progressive education aligns with Dewey's steps of learning, which are essentially the same as the scientific method:

1. Cite a problem.
2. Propose hypotheses to solve problem.
3. Evaluate the consequences of the hypothesis from one's past experiences.
4. Test the most likely solution.

Theoretically, progressive education also emphasizes life-long learning and the development of social skills, not the mere ability to perform well on a test. Progressive educational ideology, then, is staunchly opposed to the NCLB legislation as it has encouraged "teaching to the test," a behaviorist attitude, rather than "learning by doing," a fundamentally constructivist attitude.

Constructivism and Progressivism: Inquiry Learning

The progressivist and constructivist approaches to education view students as responsible for what they learn. Students are viewed as thinking individuals who already have theories about their world, are capable of making new theories, and are capable of reinvestigating and revising old theories. Teachers in a progressivist classroom control the environment of the classroom and interact with the students. The classroom serves as a place where students can interact with the teacher and with others in order to increase their understanding and critical thinking skills. Learning occurs through a trial-and-error process rather than a note-taking process. Assessments in a constructivist atmosphere may not necessarily involve standard tests. Commonly, students are assessed on the quality of their work and through alternative assessments like exhibitions and portfolios. This type of education has been called authentic learning because it models how students would most likely learn in the real world. For simplicity's sake, the term "student-centered learning" will be used for the rest of the paper when referring to learning methods that are hands-on, authentic, inquiry-based, and involving activities in which the students must make "some decisions about what they are doing and what their work means" (Colburn, 2003).

At the most general level, inquiry is the student's path to discovery. Simply, the process of inquiry is a process of "asking questions and finding answers" (French, 2005). It is an authentic method that most people use to solve daily problems when there is no authority figure to tell them the best answer before they encounter the problem. People are motivated to solve their problems to make their life easier; for example, if the regular road to work is not open, most people would find another route to take to work. They would use reasoning to plan a solution. It may be unfamiliar territory and may not always work out right the first time, but the persistent driver eventually arrives at work. Then, the next time the road is out, the driver has a better idea of what course of action to take. If one path was unsuccessful the first time, then the driver most likely will never try that path again.

This simple analogy seems self-evident, but in an educational setting when a teacher is available, students usually prefer to take the easier route by listening to the teacher while not exercising their own brains in problem-solving. In the driving analogy, if a teacher were in the car and knew an alternative route to work, it would be easiest and save time if the teacher told the student how to get to work and the student mindlessly followed the directions. But the next time the student is in the same position with the same road closed and without a teacher, the student will have trouble finding the same way unless the directions were repeatedly drilled into the student's memory. If the student had to deal with a completely new road closing without the aid of a teacher, the student has no previous experiences from which to draw guidance. Not having a teacher in the car means there will be no directions. However, if the student were lost and the teacher were present, if the teacher explained the steps of solving the problem and encouraged the student to think about the problem and possible solutions, then the next time the student is alone and lost, he or she will have an experience to draw on. In this analogy, the "directions" represent the cognitive problems that humans must address throughout their lifetimes, whether in a structured learning environment or not.

This is the essence of inquiry learning: helping students help themselves educationally. The steps of inquiry are similar to the scientific method. Here is a synopsis of the steps:

1. Inquisition: defining a question to be investigated
2. Acquisition: thinking about possible solutions
3. Supposition: selecting a possible solution to try
4. Implementation: carrying out the plan
5. Summation: collecting evidence and drawing conclusions

This type of classroom environment has been the subject of experiments in both real classrooms with teachers not specifically trained in the constructivist classroom model and under more controlled settings by educational researchers. Advocates of a constructivist approach to public education cite increases in reasoning ability as one of the most important advantages of this method (Johnson & Lawson, 1998).

It has been noted that the role of the teacher in an active classroom is harder to perform than the traditional teacher role of lecturing (Tobin, Kahle, & Fraizer, 1990). When students are taking on some of the responsibility, the teacher must adapt to students' methods of learning in order to assist the students. While the teacher may anticipate some learning scenarios, there is more variability in an authentic-learning classroom. Several studies have shown that with proper training, it is realistic to expect novice teachers to perform the role of facilitator in a student-centered classroom (Crawford, 1999).

Cognitive Load Theory

The Cognitive Load Theory (CLT) of Learning, proposed by J. Sweller (Kearsley, 2007b) takes a more physiological view of learning. The theory is based on several assumptions: the brain has two holding areas for information, short-term memory (working memory) and long-term memory; in order for learning to occur, knowledge must be processed from the short-term memory into the long-term memory; short-term memory is limited in the number of elements (discrete packets of information) that it can contain simultaneously. Implications of CLT in the educational setting revolve around the notion of reducing the cognitive load on students in order to maximize the amount of knowledge that is processed into the long-term memory structure and thus maximize the amount of learning. CLT agrees with constructivism in that knowledge must be built into the existing framework of an individual's memory, but it gives no proposal as to how the information is received in the short-term memory, only to how much information is received in the short-term memory (Kearsley, 2007b).

Summary of Learning Theories

The similarities between constructivism and progressivism can be summed up in one sentence: Teachers should not stand in front of the students and lecture to them. Meanwhile, behaviorism argues that the most reliable and efficient method of eliciting desired behavior from students is to directly tell students information and how to solve specific problems. CLT suggests that there is a limit to the amount of new information that can be absorbed during any given time interval, which would explain why students do not always remember all of a lecture or all the steps involved with solving a specific type of problem. This would also explain why recitation of information and practicing of problem-solving skills are usually necessary for the understanding of a concept. Recitation and practice are student-centered activities that provide support for the construction of knowledge. In addition to student-centered practice, progressivism proposes that recitation and practice are more interesting and more applicable in a real-life or quasi-real-life environment. Despite the good intentions of these theories of learning and cognition, no theory has risen to the status of a unanimously agreed-upon law-of-education upon which educators can base their teaching practice and legislators can base their legislation.

Learning Styles

Theory of Multiple Intelligences

The theory of multiple intelligences (TMI), proposed by Howard Gardner in 1981, provides a different feature of learning theory not described by behaviorism or constructivism-- that all individuals have a unique “cognitive profile” which guides one’s learning and understanding. The theory challenges the perception of intelligence as the behavior of achieving a good score on an IQ test and suggests that all students cannot be lumped into one category because different people construct their knowledge in different ways. In an effort to categorize the diverse cognitive states of the population, Gardner proposed eight areas in which intelligence can be manifested: bodily-kinesthetic, interpersonal, linguistic, logical-mathematical, naturalistic, intrapersonal, spatial, and musical (Gardner, 2003). The application of Gardner's theory to education has resulted in a call for more diverse methodologies that do not simply cater to individuals with logical and linguistic intelligences.

While traditional schools in the United States focus on logical and linguistic intelligence, some schools in the U.S. fully embrace the TMI. Harvard conducted a study of 41 of these schools with the conclusion that the schools had a "culture of hard work, respect, and caring; a faculty that collaborated and learned from each other; classrooms that engaged students through constrained but meaningful choices and a sharp focus on enabling students to produce high-quality work" (Kornhaber, 2004). Critics of the theory point to a lack of empirical research to support Gardner's claims, as well as the incompatibility with the neuro-scientific view of cognition (Gilman, 2001).

Intellectual Styles

The concept of individual intellectual styles (IS), somewhat related to Howard's TMI, may also be considered when discussing instructional methods. IS refers to "one's preferred way of processing information and dealing with tasks," and research shows that most people habitually use the same method of processing information, regardless of the nature of the learning task (Zhang & Sternberg, 2006). Economically, IS is more important than TMI or learning theories because IS theory is more concerned with what type of IS is most conducive to innovative intellectual work, rather than focusing on how individual students best retain information. Until the last few decades, intellectual styles were regarded as different but equal (value-free); no specific style was thought to be superior to others. Newer research shows that intellectual styles that are adaptive are superior to styles that are not and that some characteristics of IS consistently correlate to higher academic performance and other positive social behaviors and thus are value-laden (Zhang & Sternberg, 2006). Furthermore, IS is malleable. Therefore, catering to a specific IS is not discriminatory toward students not currently using the style, but helps those students adapt to using the more valued IS in their intellectual pursuits.

Many models have been proposed in order to classify intellectual styles, so much that the field of intellectual styles is overgrown, overlapping, and incomprehensible. Zhang and Sternberg have simplified the overlapping styles from the many attempts of others to describing the field of learning styles. They suggest three broad intellectual styles. Type I people have a deep learning approach, a holistic mode of thinking, an innovative decision-making style, a divergent thinking structure of intellect, and a field independent perceptual style. Type I, field-independent people are inclined to think and act creatively (Miller, 2007). Type II people take a surface approach to learning, have an analytic mode of thinking, an adaptive decision-making style, a convergent structure of intellect, and a field dependent perceptual style. Type II people are more adept at structured tasks, memorization, and following situational norms. Type III people are somewhat of a mixture of type I and type II styles. Their response depends on the nature of the task and may respond either in a type I fashion or a type II fashion. Type III people tend to have an achievement-centered learning approach, integrative modes of thinking, and realistic personality types (Zhang and Sternberg, 2006).

While people do tend to exhibit one of the three intellectual styles, it has been proposed that intellectual styles are malleable and that adaptation may occur by meeting the demands of a learning environment (socialization) and as a result of intentional instruction. Researchers have found that "if people stay in an environment that requires the use of a particular style for prolonged periods of time, it is likely they will form new ways of dealing with their environment, that is, new styles" (Zhang & Sternberg, 2006).

The style research supports the conclusion that educational environments should be selective for style traits that are socially desirable. This does not negate the need for a diversification of intellectual styles, but suggests that if innovation and scientific ability are lacking in our culture, a new kind of learning environment may shift the IS in the US away from a predominance of type II people. The type I intellectual styles, non-structured, complex, non-conforming, and autonomous, are highly regarded in the scientific community, and Morgen (1997) has shown that field-independent students (type I) tend to major in science-related subjects, whereas field-dependent students are more likely to be human service majors (teachers and social workers). Devore (1984) has found that science teachers with a field-independent (type I) intellectual style report more positive attitudes towards teaching science. Koppelman (1980) and Serafino (1979) have shown that field-independent teachers tend to ask reasoning questions rather than memory questions.

Research suggests that intellectual style is malleable and, as stated above, some styles are superior to others when learning. Instead of founding teaching practices on an individual's intellectual style, if students' could adapt their methods of processing information to include type I characteristics, more students would benefit by having skills that are in demand in the global economy. Also, the national economy would benefit by having access to workers with type I traits.

Creativity

"Creativity is the ultimate economic resource" (Florida, 2002). Creativity, or originality, is also a central part of practicing science; yet for all its importance, it is not measured by standardized tests that supposedly predict scientific ability. Creativity sets humans apart from other animals whose behavior relies mainly on instinct and genetics (Kim, 2007). For some, creativity is a congenital gift. For others, finding creativity is the most difficult part of any project. Ray (1967) contends that "people are naturally original, and the quantity of originality can be increased." Like most acquired skills, original thinking is harder for some students than for others, but practicing originality can help all students reach their individual innovative potential (Tan, 2007).

Students should not be expected to discover novel ideas, but they should be encouraged and expected to discover or rediscover ideas for themselves. If students have a correct view of science as an ever-changing expanse of knowledge, not just a subject, they may be more inclined to produce original, creative ideas because they understand that science is not static with predetermined right and wrong answers. This probabilistic understanding of science is more exciting than the stagnant view of science and should be emphasized to all students as a means of recruiting future scientists and engineers.

Unfortunately, students struggle with the creativity necessary to create a scientific hypothesis without copious amounts of direction. Ray (1967) determined that this deficiency is a result of students being told how to think from primary school onwards and experiencing positive reinforcement only when producing the correct answer. In order for students to feel comfortable displaying multiple ideas or solutions, they should be reinforced for the quantity and originality of ideas or solutions without evaluating the practicality of the ideas. Later, in an evaluation period, students should begin reasoning to choose an idea that is most sensible.

Teachers who exhibit original thinking, or “role-model creativity,” can foster an environment of creative learning which may potentially impact students for the rest of their lives by changing the way the students approach problem solving, information processing, and their willingness to take risks (Sternberg, 2007). Practical methods for reinforcing and increasing original thinking have been suggested by Osborn (1957) and Gordon (1961). Osborn writes that the practice of brainstorming makes students more likely to consider a large number of ideas when addressing a problem. Gordon proposes that synectics, “the joining together of different and apparently irrelevant elements,” helps facilitate the linkage of new information to already mastered information and make concepts less abstract. This method of thinking is useful in making ideas that are hard to conceptualize more coherent. Gordon gives the example of a chemist “personally identifying with molecules in action.” By this, Gordon means that the chemist pretends to be the molecule and interacts with other molecules according to the surrounding forces. This original thinking and behavior allows the chemist to think of the situation in a concrete manner and may lead to insight about the nature of chemistry. Other strategies to encourage students to use creative thinking skills include hypothetical thinking, role reversal, application of different symbol systems, making analogies, taking an alternate point of view, completion or “what is missing?” and web analysis (or concept mapping:

simple parts can combine in different ways to form a complex whole) (Cardellichio & Field, 1997).

Teaching students to think for themselves is by far the greatest lesson. This lesson equips students for more than just multiple-choice tests on memorized facts and algorithms. If students are equipped with thinking skills, they are more likely to fill in their own educational blanks and will no longer depend on the government to assure their education. The resources exist for self-teaching to be the goal of all education systems. The Internet is one of the most important educational advances in the history of the world. An Internet connection gives students access to more information than a person could read in a lifetime. Psychological theories concerning creativity are educationally important if the goal of education is to teach students to use their ability to think beyond the scope of information generally accepted as fact rather than to merely understand what has come from the creativity of others.

Motivation

Motivation is closely related to creativity because in order to think creatively there must be some impetus. Students in the U.S. are generally not lacking in resources for a wonderful education, but the lack of motivation of students is perhaps the most difficult obstacle that a teacher must overcome. The adolescent mind's under-developed prefrontal cortex, believed to be necessary for executive function and self-control, is more likely to make decisions in favor of immediate gratification instead of delayed gratification (Crawford, 2007), which generally leads to more considerable rewards. Therefore, education must compete with the many other sources of fulfillment available in today's society.   While it is unrealistic to think that all students can be persuaded to thoroughly enjoy their classes and be thankful for the opportunity to learn when so many other adolescents are not as fortunate, social scientists have studied human motivation in order to ascertain the most effective ways to motivate learning.

Intrinsic motivation (from within an individual) is almost invariably more important that extrinsic motivation (from an external source) when considering learning (Sullo, 2007). Thus, internal motivation is more important than the external motivation of achieving high grades. Adolescents are generally motivated by what they consider relevant and under their control (Crawford, 2007).

Self-regulation is a key facet of intrinsic motivation, and behavioral research suggests that the average child in the 21st century is less self-regulated that the average child of the mid 20^{th} century. Self-regulation is a "mechanism that underlies intentional, mindful, and thoughtful behaviors;" it allows people to control impulses and both initiate and inhibit behavior (Bodrova & Leong, 2005). In the 1940s, psychologists asked children of ages 3, 5, and 7 to do specific exercises. One exercise was to stand perfectly still. Three-year-olds were unable to stay still, five-year-olds were able to stay still for an average of 3 minutes, and seven-year-olds were able to stand still for as long as they were asked to do so (Speigel, 2008). When Elena Bodrova repeated this study in 2001 she found that today's five-year-olds behave like three-year-olds did 60 years ago and that today's seven-year-olds behave like five-year-olds did 60 years ago. This diminished self-regulation most likely affects children into adolescence and pre-adulthood-- during the most important years of formal education (Bodrova & Leong, 2005). Often a lack of self-regulation is treated with a "they will grow out of it" attitude; however, poor self-regulation is linked to dropping out of school, drug abuse, and criminal activity (Henry, Caspi, Moffitt, Harrington & Silva, 1999; Crockett, Raffaelli, & Shen, 2006). If students do not practice self-regulation, they will not learn self-regulation.

Teacher-controlled educational environments from kindergarten onward are believed to inhibit self-regulation. When a teacher is control of all classroom activities, students do not become prepared to initiate any educational behaviors on their own (Bodrova & Leong, 2005). While children 60 years ago were also in teacher-centered classrooms, the major difference is the type of play that children now participate in versus the play of 60 years ago. Sixty years ago, the toys that children played with required more imagination. For instance, a cardboard box could be a car to drive around in or could be turned over and become a table for a tea party. Children had to plan and think about what they wanted to play and then act to create that environment. Today, toys are less likely to require children to actively think about the play situation and merely to follow cues from toys. Children cannot change the rules or the goal of video games, and a plastic cell phone will only be used to play-talk, emulating adult behavior but not using imagination and self-regulation (Speigel, 2008). As the type of play has changed, it has become even more important to teach students self-regulation in the K-12 classroom and beyond because students may not develop it from at-home life. The best way to teach self-regulation and self-reliance is to allow students to engage in academic projects where they must plan and perform a course of action.

Students must be internally motivated to engage in self-directed action, and students are more motivated by situations where they perceive control (Skinner, Zimmer-Gembeck, Connell, & Eccles, 1998; Dweck & Leggett, 1988). The impetus for creating a classroom that motivates students to appropriately self-direct their learning should implore basic human needs. Bob Sullo (2007) lists a model for describing human behavior based on fundamental needs that is more complex than the reward-punishment model. Most behavior can be described by one or more of the following basic needs: belonging, power, freedom, fun, and survival. Educational environments that are structured to meet these needs of students will make students more motivated to actively engage. Once students are internally motivated to take responsibility for their own learning, this motivation is augmented by the internal satisfaction of a job well done and the boost in self-esteem created by enabling students to have control over what they learn. The reward for work done as a result of internal motivation is much greater than the reward for completing externally motivated tasks.

Conclusion

Learning, intellectual, creativity, and motivational theories provide a basis for considering how to achieve a practical and coherent educational theory. While there is some empirical evidence for statements pertaining to individual theories, there is an enormous amount of variables in an educational setting. Since many variables are out of the control of the instructor and researcher, the impact and practicality of these theories are arguable. However, at this time, they are the most accepted theories. Some would consider two or more of the theories presented in this paper to be completely dichotomous, but it is the goal of the researcher to pick out what appear to be the most beneficial ideas from each theory and construct the parts into one theoretical foundation. The overarching points of the collective theories include the following tenents: The best way to assess learning is through behavior, although the type of assessment behavior may be variable and should be varied. Students are capable of thinking for themselves and should practice this behavior often to maximize their ability to think independently and creatively. Intellectual styles appear to be malleable, and valuable styles of thinking can be learned. Some control over concept complexity should be used when first discussing entirely novel ideas in light of the cognitive load theory. It is thought to be advantageous for students to acclimatize themselves to the concept in a slow and thoughtful process to avoid cognitive overload and confusion. Lastly, when students can take responsibility for and pride in their own educational success, they are motivated to continue on that path.

CHAPTER III

REVIEW OF EMPERICAL RESEARCH

There has been a call for more educational research in both the U.S. and Britain following the apparent decline in each nation's educational system in order to make teaching a more research-based profession and to make the process of education more evidence based (Biesta, 2007). Cognition and learning are complex processes that scientists and psychologists have tried to decipher for years, but due to the limitations of educational research (as described in the introduction), unequivocal conclusions are difficult to find. Therefore, it is necessary to review a large amount of research in order to predict the learning and educational theories, paradigms, and techniques that have the highest probability of generating success in the classroom. Looking at this problem from many perspectives is ideal; empirical neuroscience research will be considered in addition to empirical research in educational settings.

Neuroscience Research

While earlier scientists had to purely speculate how brain structure and function are related to the abstractions of thinking and behavior, emerging imaging methods such as magnetic resonance imaging (MRI) allow scientists to get a closer glimpse of brain function (Nobel, Tottenham, & Casey, 2005). Research of brain structure and neurons has led scientists to intriguing discoveries. At birth, the human brain has more than 40 different areas that have been designated as functional regions for specific tasks such as vision, hearing, language, and muscle movement (Lowery, 1998). When an individual experiences several different types of stimuli simultaneously, the information is fragmented into various regions of the brain for storage, but the fragments of a particular memory are still associated with each other through neural connections. Upon recall of the experience, the fragments are collected from the various regions and are re-associated to create the memory (Lowery, 1998). This re-association of the components of a memory or of a learned process enhances the neural connections between the components, and the brain learns the process of recalling connected information, especially when the brain frequently re-associates the information and calls the information into the working memory.

When sensory information is delivered to the brain, the brain processes the information by seeking to find a connection with what it has previously experienced (Crawford, 2007) and "hook the unfamiliar with something familiar" (Wolfe, 2001). Novel experiences perceived through the senses cause brain cells to develop new connections. The brain structurally changes itself to cope with the new situation, and the brain organizes and reorganizes information (Crawford, 2007). The new neural connections can be used to specifically process particular pieces of information. Just one cell can have as many as 100,000 connections (Cardellichio & Field, 1997). However, connections may not be permanent. Most people have learned from experience that when information is recalled or used often it is easier to remember than information that is rarely recalled. This cognitive phenomenon of decreased recall ability has been given the name "neural pruning." Through neural pruning, connections that are not frequently used for recall of information are eliminated. The removal of unnecessary connections is another method that allows the brain to adapt itself to its environment (Crawford, 2007).

One detrimental effect of neural pruning is that the neural pathways that are reinforced and frequently used can limit the way new information is perceived. In other words, the brain can oversimplify ideas by using pre-existing, rigid neural networks to incorporate new information rather than expanding the neural network to accommodate the new ideas. If the new knowledge is not compatible with the rigid neural network, it may not be incorporated (Mulford & Robinson, 2002). Although the brain has the ability to be plastic (Diamond, 1967), the brain seems to become fairly rigid when a narrow range of experiences cause the brain to narrowly perceive information. Strong misconceptions may be formed when students use pre-constructed neural pathways to analyze concepts that do not overlap (or are incongruent) with students' preexisting neural pathways (Cardellicho, 2004). By forming new branching neurons, the brain's learning capacity is increased, and educators should focus on teaching strategies that increase brain plasticity such as inquiry-based learning with ample feedback (Crawford, 2007).

A substantial amount of research has shown that learning is related to increased neural connections (Abumrad, 2007). The opposite of neural pruning, neural branching, is thought to occur when ideas, thoughts, concepts, and pieces of information are recurrently "used," or brought into the working memory. It is generally accepted that the more neural connections one has, the higher the brain functioning, and that the more a neural connection is "used" or accessed, the stronger the connection. Brain scans on primates before and after they have learned a task show that the experiences change their brain structure and that this change in brain structure is correlated to a primate's ability to engage in novel behavior and thinking with "surprising connections to human thought and behavior" (Bower, 2007).

A study conducted by Elizabeth Gould (Abumrad, 2007), professor of psychology at Princeton University, is particularly edifying. Three groups of primates were placed in three different living situations. One living situation was enriched: full of brain-stimulating toys, trees to climb, and other primates to interact with. A second group inhabited an intermediately enriched environment in which they had access to a few toys, but overall, had a less stimulating environment. A third group lived in a cement room. At the end of the experiment, the primates' brains were dissected, revealing that the more stimulating the environment, the more neurons and the more neural connections in the primates' brain. The researchers did not force or encourage the primates to play with their toys; the toys were simply accessible. The inherent curiosity of the animals led to increased neural connectivity. The ability of scientists to cause physiologically discernable neural changes in animals by controlling the animals' environment has been corroborated by other researchers as well (Nobel, et al., 2005; Rosenweig & Bennett, 1996).

Gould's research (Abumrad, 2007) and other studies (Nobel et al., 2005) have shown that stressful conditions caused by social hierarchy (bullying), unpleasant noises, and boring environments may cause the brain to stop creating new cells. This theory may be imperative for the design of techniques used to decrease the achievement gaps seen in the U.S. between different races. Students living with poverty and stress may be at an anatomical disadvantage compared to other students. If this hypothesis is true, no amount of teaching or strategy of teaching will cause significant, long-term learning if the student is not making new neural connections. Although schools will not be able to alleviate the social stresses of students' lives outside of school, a non-stressful classroom environment may be one of the most important factors to enhancing neural connections and thus learning.

While cognitive stimulation does increase neural connections, the link between neuroscience and educational practices is still largely unknown (Bruer, 1997). What is known is that empirical research indicates that the brain is plastic and that educational interventions have been shown to increase neural activity in pre- and post-MRIs of subjects engaged in cognitive activities (Nobel et al., 2005).

Research in Educational Settings

Unguided Learning Research

Pure discovery learning methods do not have a good track record in published research. In 1956, Craig found that when students are given logic problems (for instance, which object or word does not belong in the group?), students in a discovery group who received no guidance on how to solve the problems learned less and learned less efficiently than students in a guided-discovery group in which students were given hints but were not given answers or rules.

In 1957, Kittle performed a similar experiment to that of Craig (1956) but added a third group of students who received pure expository teaching where students were told rules for solving logic problems and given answers to logic problems. Kittle found that the pure discovery group had the worst immediate retention, delayed retention, and transfer to new problems. The expository group displayed intermediate results and the guided discovery group had the best immediate and delayed retention, as well as the best ability to transfer their problem-solving strategies to new problems. Shulman and Keisler found the same result in 1966.

These studies in the 1950s and 1960s show that without guidance students do not perform as well as students who receive guidance and that students who are guided to find answers to problems perform better than students who are told how to solve problems. In more recent times, the debate over instructional style is still ongoing. Kirschner, Sweller, and Clark published a paper in the *Educational Psychologist* in 2004 titled “Why unguided learning does not work.” In this paper, the authors cite 25 studies that fail to support unguided and minimally guided learning experiences. Some studies cited in the paper not only fail to support unguided learning but conclude that it is detrimental to novice learners and less efficient for more experienced learners. The authors are in favor of strongly guided, teacher-centered transmission of knowledge and problem-solving techniques to decrease the amount of cognitive load students incur.

Other arguments against student-centered learning include the following. Gabel (1999) concluded that typical students do not interpret their observations and results and, therefore, have a hard time generalizing the results of the laboratory to basic chemistry concepts. Hofstein & Luneta (1982) agree with Gabel and have found that laboratory activities have little effect on student achievement.

In 1938, Dewey suggested that free-wheeling students do not “structure their learning experiences for maximum benefit,” and this is a major hindrance of free student-driven education. Carlson, Lundy, and Schneider (1992) also noted that students often make several attempts at finding the right path, and that these unguided learning situations are a misuse of valuable time. Research from both Brown & Campions (1994) and Hardiman, Pollatsek, & Weil (1986) found that when minimal amounts of feedback are given, students become frustrated and are more likely to have misconceptions about the material. Additionally, Mayer (2001) found that when students are directly given information, they have a higher rate of fact recall and correct use of problem-solving skills. Kirschner et al. (2004) agree and specifically cited cognitive load theory as the reason that unguided learning does not work; they theorize that the unguided learning of complex concepts puts too much information in the working memory and this information overload hinders the amount of information that can be processed into long-term memory. In research related to this theory, Sweller (1999) found that students learn more when solving a problem to which they have an answer as opposed to problem solving without an answer and that students are able to work a similar problem without an answer only after sufficiently study of the worked problem.

Klahr and Nigam (2004) attempted to determine whether direct teaching or discovery learning would be more effective at prompting students to design unconfounded scientific experiments. In this two-day study, one group of third- and fourth-grade students were treated with an “extreme” (p. 662) direct instruction. “Extreme” direct instruction was defined as the instructor’s having complete control of goals, materials, examples, and explanations. The objective of the lesson was to have students determine how the variables of a ball’s material and the surface, length, and steepness of a ramp affected the distance that a ball traveled after rolling down an incline. The other group was presented the same control-variable problem, but students were asked to design their own procedure and were not given instruction or feedback on their determination of how the variables affect the distance that a ball traveled. Klahr and Nigam (2004) concluded that the directly taught group performed better than the discovery-learning students in the subsequent design of other scientific experiments and in the ability to evaluate the quality of others' control-variable scientific experiments. They found that 75% of the directly-taught students were able to design at least 3 unconfounded experiments out of a possible 4 and that only 24% of students in the discovery learning group were able to design at least 3 out of 4 unconfounded experiments.

Besides the argument that the large cognitive load associated with student-centered, minimally-guided learning impairs learning, students' feelings towards learning may also affect the effectiveness of student-centered learning. Muis (2007) found that student's epistemic beliefs are related to self-regulation of learning and motivation to learn. Thus, if students do not believe that they can increase their knowledge if they try, then they are not motivated to try to learn. These students rely on others to tell them information without trying to internalize it. Self-regulation of learning is a necessary component of learning by inquiry, and students who do not have a positive view of their ability to learn perform poorly in inquiry-based classes.

Research Supporting Student-Centered Educational Techniques

Many educational researchers have come to conclusions that are opposite of those cited by Kirschner, Sweller, and Clark (2004). These researchers have been able to substantiate the claim that student-centered learning is just as effective as teacher-directed learning, and some researchers have concluded that student-centered instructional methods result in a higher student performance over teacher-directed learning methods. Some studies show no major difference in the concept mastery achieved by students in a student-centered environment and those in a teacher-directed environment, but do claim alternative benefits to students' participating in student-centered classrooms.

Sanger (2007) sought to answer the question: "Do students learning chemistry using different instructional methodologies (inquiry-based lessons versus traditional lecture format) develop a comparable chemistry content knowledge?" He taught an inquiry-based chemistry class to elementary education majors while simultaneously teaching chemistry by lecture to science majors and compared the students' achievement at the end of the semester. The inquiry-based class was taught entirely in a laboratory-discussion setting in which students performed experiments, analyzed data, and applied their learning to new situations. The traditional lecture class used for comparison consisted of 3 hours of lecture and 3 hours of lab per week. Both classes developed similar chemistry content comprehension when evaluated with the same content questions. Although the students taught via inquiry scored higher than the students taught via lecture on all topics, the difference was statistically insignificant. While both classes were able to perform similarly on exams, this experiment did not examine students' potential to increase, decrease, or remain unchanged in any type of desirable intellectual characteristic, such as type 1, field-independent behavior. However, because the testing outcomes were similar, the experiment does alleviate charges by some who believe that inquiry science classes are watered-down versions of science for less able students (French, 2005).

Oliver-Hoya, Allen, Hunt, Hudson, and Pitts (2004) describe an experiment where one instructor taught two sections of the same class, but the instructor used a different instructional method for each class. One class consisted of a conventional lecture with a separate lab. The experimental class was a hands-on, collaborative, inquiry-based environment supported by mini-lectures between activities. Both classes were assessed with similar exams. Despite the large size of the experimental class (N=99), which limited the amount of direct teacher-student interactions, the bottom 25% of the inquiry class performed better than the bottom 25% of the lecture class on the last three exams. These data suggest that teaching via inquiry is more beneficial for the bottom quarter of the class while not being detrimental to the upper three quarters. The experimental class was not performing significantly better than the traditional class during the first half of the class which suggests that students may need time to adjust to the inquiry method before they begin to perform better.

In a 1997 study, Johnson and Lawson evaluated 366 students' reasoning ability, assessed prior biology knowledge, and recorded the number of previous science classes that each student had taken. Half the students were taught biology in a student-centered environment, and the other half were taught the same material, but in a lecture format. Students were evaluated using the same exams. The test averages in both classes were consistent. Prior knowledge and the number of previous science courses that a student had taken were not significant predictors of success (determined by final grade) in either classroom setting. In both classrooms, prior reasoning ability was a successful predictor of student performance. The interesting conclusion of this study was that after the course was over and students had taken a post-class reasoning assessment, students in the lecture class did not show any changes in reasoning skills, but students in the inquiry-based class did have significant increases in reasoning ability, especially for students who scored lowest on the pre-class reasoning ability test. Since reasoning ability turned out to be a good predictor of class success, students who have strengthened their reasoning skills are probably more prepared then they would have been for future problem solving both in other classes and in future professions. Reasoning ability is a cognitive characteristic wanted by prospective employers worldwide, and teaching methods that develop reasoning ability should be emphasized in U.S. schools.

Kuhn and Dean (2007) found evidence of the effectiveness of authentic-type learning in the "long view," referring over long periods of time and in different contexts. Kuhn and Dean designed their research in response to the two-day study by Klahr and Nigam (2004) described in the previous section. Klahr and Nigam attempted to determine whether direct teaching or discovery learning would be more effective at prompting students to design unconfounded scientific experiments. The fact that the Klahn and Nigam study only determined the effect of teaching strategy on competencies for two days led Kuhn and Dean to ask how student competencies would be affected by teaching strategy in the long view. They hypothesized that direct instruction may produce one-time results, but that the students would not likely reap the long-term benefits of the knowledge. Kuhn and Dean found that there are not significant differences in the grades of students taught directly or via authentic learning, but that students who engage in authentic learning are more likely to use the information later and be able to apply it in different contexts.

Structured peer teaching has been shown to be an effective student-centered learning technique that is also beneficial in the long run. A study of 3,268 students compared the instructional techniques of students' high school teachers with their performance in college chemistry courses (Tai & Sadler, 2007). A positive correlation was found between structured peer teaching and success in college chemistry. A less significant correlation was found between use of everyday examples and success in college chemistry. Structured peer teaching gives students control over how they are learning, but is closely supervised by the instructor so that students keep on the right track and can ask questions if necessary.

House (2006) found a positive correlation between six instructional strategies and high science scores on the 2003 TIMSS. Frequent in class experiments, working in pairs or small groups, teacher demonstrations of experiments, copying notes from the board, working on science projects, and using everyday life situations when solving science problems were positively correlated with higher science scores. Lower TIMSS science test scores were related to students who indicated that their teacher frequently showed them how to do science problems and students who reported working quietly on worksheets and textbook problems during class time.

Of the six classroom techniques that are correlated to higher TIMSS scores, 3 are student-centered (experiments, small group work, and science projects), and two could be described as progressive (teacher demonstrations and using everyday life situations to solve science problems); copying notes off the board could be described as straight knowledge transmission and may be necessary for learning science concepts that cannot be demonstrated in class. Of the two techniques correlated to poor science scores on the

2003 TIMSS, neither would be considered student-centered analysis or progressive. These data suggest that guided, student-centered classroom techniques coupled with traditional classroom methods like copying notes off the board are effective in producing higher scores on the TIMSS. The TIMSS purports to test knowledge of concepts and of reasoning ability (CITE). It has not been demonstrated, however, that high scores on the TIMSS lead to higher economic productivity.

Comparison of Research

An overall review of in-classroom research literature appears to be diametrically conflicting in regard to the amount of control students have in their learning. There does seem to be considerably more written about student-centered methods which gives the appearance that the majority of science education literature supports student-centered and progressive learning. A common theme of the research cited by Kirscher et al. (2004), Craig (1956), Kittle (1957), Klahr & Nigam (2004), Mayer (2001), and Muis (2007) is that unguided learning does not work. Compared to the research that supports inquiry-based, student-centered learning, there is an inconsistency in the level of student guidance. Research that supports inquiry-based learning also supports teacher guidance. Some assert that teaching by inquiry is more difficult than preparing a structured lecture with solved problems because the instructor needs to keep up with the ideas of all the students in order to guide them properly. But, this kind of guidance facilitates a reliance of students on the instructor and a reliance of students on each other. In order for students to keep frustration at bay, they need a constant source of guidance from teachers, other students, and reference materials. If one source is unavailable, they have other sources of guidance. Although student-centered teaching becomes increasingly difficult when class sizes are large, advances in technology are currently making this type of classroom available to students enrolled in large classes. The use of technology allows teachers to glean information from their students about where are conceptually and where students' difficulties lie.

The most accepted and published argument against completely unguided-learning is that this free exploration method overloads students' working memory, which reduces long-term learning achievement for students (Moreno, 2004). A treatment for this conflicting attribute of authentic learning has been recommended by Roxana Moreno from the University of New Mexico. She has researched the effectiveness of using explanatory feedback when guiding novice students in authentic activities. With Moreno's practice, teachers guide students using explanatory feedback by concurrently discussing students' choices with detailed explanations rather than simply telling students if they are on the right track or not. This transforms unsuccessful attempts or ideas into a learning situations rather than frustrating wastes of time. By using a method of explanatory feedback, the instructor does not need to correct the student during the discovery phase, but can simply give information to the student that may change the way he or she is thinking about the problem.

A further analysis of the educational research for and against student-centered learning experiences shows that the two different factions have two different definitions and goals of learning. Those who support traditional expository learning cite the efficiency of the method to accurately deliver the most information per unit time and the efficacy of the method regarding instantaneous and short-term recall. Those who support a more progressive, student-centered approach find the process of learning to be the most important goal of teaching, followed by long-term recall of concepts.

Most agree that student-centered learning is a slower process, and therefore, the same amount of material cannot be covered in the same amount of time (Llewellyn, 2005; Oliver-Hoya, Allen, & Anderson, 2004). If students are expected to learn a large amount of material in a short time in order to perform well on a multiple-choice exam that assesses students' recall, then the lecture format is one of the fastest ways to transfer information. Cognitively, however, a lecture is no different from a student reading the information from a book. Both transfer information from a source into the student's working memory. Books can be as well written as a lecturer's presentation complete with pictures, charts, and graphs to complement the information, essentially eliminating the need for instructors (less their grading capabilities). Whether a student learns more from a lecture or from a book depends on the student's preference for auditory versus written learning. But books and formal lectures do not provide individual student feedback.

While lecture may be the most efficient way for teachers to deliver information, it is not necessarily the most efficient way for students to learn information since students are not likely to pay attention to the whole lecture and will have to spend out-of-class time reviewing lecture topics (McKeachie, 1986). By the nature of student-based learning, students are actively engaged in the learning process so less in-class time is wasted. Thus, there may not be much of a time discrepancy between lecture and student-centered techniques, and active learning done in the class can make students' out-of-class time spent preparing for class more efficient and focused.

Proponents of student-centered learning are interested in producing a different outcome. The goal of authentic, student-centered teaching is more complicated. Instead of simply delivering information to students, teachers guide students to become self-sufficient in their own acquisition of knowledge. Teachers teach students to learn how to think and to enable students to think about how they learn. Meta-cognition allows students to be in charge of how they learn and what they learn for the rest of their lives. Despite the realization that student-centered learning takes more time than direct lecturing, the benefits of student-centered learning have the potential to make up for --and even surpass--the benefits of education by proxy.

First attempts at teaching in a style that differs from how teachers themselves were taught or from what they have been doing for years can be overwhelming due to the perceived lack of control. Most teachers are more comfortable when they control the classroom. Not only do teachers need to know the subject well, but they need to be ready at all times to answer a barrage of questions from students and keep up with all of the students' work. It is more difficult than preparing a lecture covering information that the governing authority wants students to know. Although more difficult, the authentic, student-centered method of teaching can be more rewarding than the traditional method. In traditional teaching, there are two entities in the classroom paradigm: the teacher and the students. In student-centered learning, the amount of direct interaction with students is drastically increased. When a teacher comes to know students as individuals, then the overall classroom paradigm has shifted to the teacher, student A, student B, student C, and so on. The better teachers know their students, the better they can tailor their teaching methods to the individuals. The benefits of student-centered education may be subtle but are increasingly significant for the educational advancement of students in the United States.

CHAPTER IV

SCIENTIFIC LITERACY

Introduction

One could argue that science is the most beneficial subject for students to understand because in the broadest sense, science is the systematic attainment of knowledge (of any topic) pursued by objective reasoning and sensory experience. A student who is able to think scientifically is able to translate reasoning methods to other areas to increase knowledge and understanding. In another sense of importance, the scientific study of human kind's surroundings has been the gateway for the species' evolutionary success on earth. The first signs of scientific reasoning can be seen in Paleolithic carvings of numerical records and data, and humans have prospered from the application of scientific methods to problem solving (Boyer, 2002). Also, most other subjects such as mathematics, composition, reading, and history can be enhanced in a science classroom.

Purpose of Scientific Literacy

Science literacy is important to the U.S. for future scientists and engineers as well as those not pursuing a scientifically based career. Obviously, science literacy and scientific inquiry skills provide a link between the education realm and the career world for scientists, but science also has benefits for the society in general. The current US society calls for decisions to be made every day concerning complex scientifically explained processes. Members of society make decisions about what they eat, how they interact with the environment, and what medical procedures they undergo. Citizens are called to vote on (or for or against candidates supporting) issues concerning complex scientific concepts including energy policies, environmental policies, stem-cell research, abortion and the definition of life.

Citizens rely on the government (FDA, CDC) for protection from tainted food, deadly diseases, and dangerous applications of science. Citizens expect warnings from the government when severe weather is imminent, expect the government to take care of the environment, and expect the government to fund research for a cure for cancer and AIDS. This is simply too large of a responsibility for the government to handle. Citizens could take more responsibility for themselves concerning health and science issues if they were scientifically literate.

While it is easy to leave these issues in the "hands of the professionals," US citizens in a democratic society must choose their leaders. If these citizens are scientifically ignorant, they will also be unable to discern a knowledgeable candidate from an average person and be unable to make appropriate choices while voting. The journal *Public Understanding of Science* published an article entitled "The Measurement of Civic Scientific Literacy" which estimated that only 25% of Americans and Europeans are scientifically literate by the measures of this study (67% correct answers on a concept survey) (Miller, 1998). "Education is the guardian genius of democracy." This quotation from the great Texas educator Mirabeau B. Lamar is a concise summary of the main goal of scientific literacy.

National Programs to Advance Science Literacy

The federal government has tried to encourage science literacy for all people in society. The National Academy of Sciences (NAS) was signed into law by President Abraham Lincoln in 1863 (NAS, 2008). The NAS was joined by the National Research Council (NRC) in 1916, the National Academy of Engineering in 1964, and the National Academy of Medicine in 1970. These four non-profit associations are collectively called the National Academies, and they provide a public service by furthering science and technology in the U.S. (NAS, 2008). The National Science Foundation (NSF) was voted into existence by congress in 1950 and charged to "promote the progress of science, to advance the national health, prosperity, and welfare; to secure the national defense…" (NSF, n.d.). Currently, the NSF budgets approximately $6.06 billion per year and provides funding for 20% of all federally funded research (NSF, n.d.). Additionally, the National Defense Education Act of 1958 and the Secondary Education Act of 1965 both stressed the importance of science education in the American Society (Powell, 2002). The NCLB Act of 2001 also states the importance of science education.

Clearly it is recognized by the U.S. government that science education is critical for maintaining the democracy and independence of the nation, but it is also clear that the national mandates have not affected the state of science education. While the government would like to improve science education in the United States—and no doubt science education would probably be worse than it is today without government mandates—a true commitment to science education must come from the bottom up rather than the top down.

The large, top-down, government-supported agencies have provided a great service to the teacher's of America by providing educational standards for the high school level that serve as an intermediary between high schools, colleges, and industry. This link allows high school teachers to be aware of what their students need to know to be successful in college and in a future career. This kind of dialogue between organizations allows teachers to be selective with their class time to thoroughly teach the most important concepts rather than covering every minute detail of a textbook.

Large government-supported educational agencies are also effective for conducting educational research to be used as a basis for identifying effective teaching methods and for providing definitions for words that have become muddled educational vernacular, like scientific literacy or inquiry. Scientific literacy is defined by the National Research Council (NRC): "Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity." In 1996, the National Science Teachers Association (NSTA) adopted this formal definition for science literacy which keeps teachers, administrators, and legislative bodies in sync with what the United States' goals are for science education.

Standards

The widely accepted National Science Education Standards (NSES) were designed by many individuals and groups to suggest a uniform method of producing a scientifically literate community. Funding for the NSES project came from the NSF, the U.S. Department of Education, the National Institutes of Health, and the National Academy of Sciences. The NSES physical science content standards include:

1. The structure of atoms
2. The structure and property of matter
3. Chemical reactions
4. Motions and forces
5. Conservation of energy
6. The interactions of energy and matter.

The NSTA published process standards in 1996 for kindergarten through 12th grade education. The unifying concept standards that all students are to know as a result of secondary education are:

1. Systems, order, and organization
2. Evidence, models, and explanations
3. Constancy, change, and measurement
4. Evolution and equilibrium
5. Form and function

The NSTA has recognized that after completing K-12 education, every student should have the abilities to do and understand scientific inquiry. Ability is indicated by students' performance formulating questions, making precise and unbiased observations, and interpreting data. The NSTA asserts, "If these are the abilities that all students should develop, then it is imperative that they be taught by inquiry and assessed in a way that requires they demonstrate these skills" (Siebert & McIntosh, 2001).

All states also have independent content standards (and maybe process standards) which have been becoming more and more aligned with the NSES standards. For instance the Oklahoma State Priority Academic Student Skills (PASS) Physical Science Objectives for high school include:

1. Structure and Properties of Matter
2. Motion and Forces
3. Interactions of Energy and Matter
4. The Earth System
5. The Universe

Chemical reactions are listed in addition to the structure and properties of matter specifically in the chemistry section of the PASS. The PASS process standards are as follows:

1. Observe and Measure
2. Classify
3. Experiment
4. Interpret and Communicate
5. Model
6. Inquiry

For comparison, *Chemie im Kontext,* a German collaborative project of four universities to ensure scientific literacy in public school systems, has identified six chemical concepts that must be understood in order to continue the development of further knowledge in chemistry (Nentwig et al. 2007):

1. The particulate nature of matter
2. The structure-property relationship
3. Donor-acceptor reactions

4. Energy and entropy
5. Chemical equilibrium
6. Reaction rates.

These standards are similar to those produced in the United States. This suggests that science education problems in the US are not a result of what students are being taught, but how they are being taught.

The nation's leading "experts" on science education have recognized the deficit in science education in the United States, but large federal mandates have been unable to provide significant improvements. This suggests that a bottom-up approach focusing on teachers may be more effective targeting issues in science education. The best way that national agencies can support science education is to directly support teachers with findings from empirical research and by informing teachers of clear and consistent goals. Locally, teachers need instruction on how to effectively implement process and content standards into their classroom.

CHAPTER V

METHODOLOGY

Introduction

Review of research and theories of cognition lead to the conclusion that student-centered inquiry could be an effective methodology for learning abstract concepts under the provision that the instructor supplies adequate guidance and incorporates enough instruction so that the students do not feel lost. One of the purposes of this project is to qualitatively examine whether a first-time teacher could be expected to lead students in an inquiry-based, authentic class, congruent with educational research, with the final result of producing scientifically literate students. In addition to this question, the study will also determine what student characteristics are correlated with success in an inquiry-based class and how students feel about an inquiry based class. The effectiveness of this teaching method will also be compared to specific chemistry concepts in order to determine which concepts inquiry learning may particularly complement.

Curriculum Design

The first-time instructor in this study was a graduate student in chemistry with no teaching experience. She did, however, have experience as a teaching assistant for organic and freshman-level chemistry classes at Oklahoma State University and had previously taken 6 credit hours of classes pertaining to teaching science in secondary schools. The students were enrolled in Inquiry-Based Chemistry, which is a course primarily for elementary education majors with limited exposure to chemistry. The class consisted of 13 females, 11 of whom were elementary education majors and 2 of whom were undecided. Over half of the students in the class were freshman, but there were also 3 juniors, and 3 sophomores. In addition to instilling scientific literacy into the next generation of elementary educators, the class was also to be designed to motivate future educators to be interested in science. Research suggests that when educators are interested in science, they put more effort into teaching science (Jurisevic, Glazer, Pucko, & Devetak, 2008). Understanding, perceived intrinsic ability to understand, and interest in science are especially important for elementary education majors.

The difference between understanding concepts and performing skills was emphasized throughout the course. The skill aspect of the course required students to spend time memorizing information like the names of elements and vocabulary definitions. Rote memorization is typically not held in high regard among educators because this type of learning often leads to short-term memory without being incorporated into long-term knowledge. However, efforts to discover knowledge from the conceptual side of chemistry would be lost on students with no framework to support observation of concepts from the hands-on learning.

The concepts chosen for this course were those thought necessary for achieving general science literacy as described in chapter IV. Since the students were mainly elementary education majors, basic science literacy was the main goal so that common misconceptions held by teachers do not become the misconceptions of future generations. Three criteria were taken into consideration when deciding which concepts to teach. First, chemistry programs from the United States and other countries with available information were assessed to determine what concepts chemistry educators all over the world consider to be important. Secondly, concepts where chosen that students could readily study using hands-on, scientific methods of inquiry and that could be performed with the resources already present at Oklahoma State University. Third, concepts that could be related to everyday life were chosen to enhance the potential interest of the students as suggested by House (2006) in his evaluation of teaching practices that co-occurred with high scores in science on the TIMSS.

Goals

The instructor's process goals for the semester are listed in table 1.

Table 1

Process Goals

1. Students will be able to form a testable hypothesis.
2. Students will be able to develop experimental procedures.
3. Students will recognize patterns.
4. Students will organize data into tables.
5. Students will explain evidence.
6. Students will use evidence to argue the validity of a statement.
7. Students will be able to draw pictures of their understanding.
8. Students will be familiar with the nature of science reasoning.
9. Students will recognize experimental sources of error.
10. Students will demonstrate planning before acting.
11. Students will use models.

The instructor's goals for concepts to be learned by the students during the semester included the following:

I. Problem-Solving Techniques: What methods can be used for problem-solving?

  A. Brainstorming

  B. Trial and error

  C. Look for patterns and trends

    1. Graph data

    2. Make tables

  D. Deductive reasoning

  E. Inductive reasoning

II. Fundamental forces: What is a force? What forces do I observe everyday?

  A. Gravity

  B. Electrostatic forces—opposite charges attract

    1. Magnets

    2. Protons and electrons

    3. Electrons are mobile

      a. Electroscope demonstration

      b. Balloon / hair attraction demonstration

III. Atomic structure: How did scientists discover atoms and subatomic particles?

  A. Rutherford: atoms are mostly empty space

  B. Milliken: atoms contain charged particles

  C. Bohr model: electrons orbit nucleus

  D. Electron shells, sub-shells

    1. Valence electrons and shielding electrons

IV. Periodic trends as a result of atomic structure:

How is the periodic table organized?

How does the organization of subatomic particles in an atom determine the physical characteristics (atomic mass, atomic radius, electronegativity) of an atom?

1. Atomic mass
    a. Why are there some abnormalities in a graph of atomic mass verses number of protons?
    b. Neutrons and isotopes
2. Atomic radii and effective nuclear charge
    a. Going from left to right in a period, why do atoms get smaller the more protons and electrons they have?
3. Electronegativity and effective nuclear charge

V. Bonding: How do atoms combine to form compounds (or multiatomic elemental molecules)?

A. Covalent bonding

1. Law of definite proportions
2. Valence electrons and lewis dot structures
3. Octet rule – sharing electrons
4. Review electronegativity – polar/non-polar bonds
5. Naming

B. Ionic bonding

1. Law of definite proportions

2. Review electronegativity
3. Octet rule --Atoms transfer electrons
4. Naming

C. Metallic Bonding

1. To be discussed in more detail later

VI. States of matter – Intermolecular forces: Why are some substances solid at room temperature while others are liquids or gases?

A. Phases and phase changes

1. Solids
    a. Macroscopic characteristics
    b. Atomic characteristics
    c. Density
    d. Solubility in liquids
2. Liquids
    a. Macroscopic characteristics
    b. Atomic characteristics
    c. Density
3. Gases
    a. Macroscopic characteristics
    b. Atomic characteristics
    c. Density
4. Phase changes are physical processes
    a. Atoms and molecules do not chemically change

B. Phase depends on two opposing factors: The strength of intermolecular forces and the amount of energy particles have.

1. Opposite charges attract (the fundamental force)
    a. Full charges
        i. Ion-ion
    b. Permanent partial charges
        i. Ion-dipole
        ii. Dipole-dipole
            1. Hydrogen bonding
    c. Temporary partial charges
        i. London dispersion forces

VII. Gases: What is pressure? Why do gases exert pressure?

A. Particulate view of gases

1. Computer simulation: Volume and pressure relationships (Gelder, Abraham, & Haines, 2002).
    a. Volume-pressure relationship
    b. Pressure-temperature relationship
    c. Volume-temperature relationship
    d. Number of particles and pressure relationship
2. Gaseous Diffusion

VIII. Liquids: Why do some liquid substances combine to form homogeneous solutions, while another pair of liquids will form a heterogeneous mixture?

A. Particulate view of liquids

1. Density
2. Solutions
3. Miscibility
4. Capillary action
5. Solubility of solids in liquids

IX. Solids: Why do some solids dissolve in water while other solids do not?

Why do boats made of iron or steel (dense metals) float on water?

Why do some solids conduct electricity while others so not?

A. Particulate view of solids

B. Buoyancy of solids in liquids

C. Metallic bonding

1. Delocalized electrons
2. Characteristics of metals

X. Chemical reactions: How does one form of matter become another form of matter with different properties?

A. Macroscopic observations

1. Color changes
2. Formation of a gas
3. Evolution of heat energy from chemical bond energy (exothermic)
4. Capture of heat from environment to break reactant bonds (endothermic)
5. Macroscopic stoichiometry

B. Atomic level observations (Abraham, Gelder, & Greenbowe, 2007).

1. Bonds Break (requires energy)

2. Bonds Form (releases energy)

3. Atomic level stoichiometry

XI. Types of Chemical Reactions: What are the basic types of chemical reactions?

A. Double displacement

1. Precipitation reactions

B. Single displacement

1. Metal oxidation-reduction reactions

C. Combustion

1. Internal combustion engine

2. Gas heating/cooking

D. Acids and base

1. Hydrogen ion exchange

2. Digestion

3. Physiological pH

In-Class Strategies

Lecture

Class time was not spent on didactic lectures of definitions and chemical verbiage so that students could have the maximum amount of time allotted for performing inquiries along with other students and under the close supervision of the instructor. Therefore, most class meetings consisted of relatively little direct lecture and more one-on-one student-student and teacher-student interactions. While memorization of chemical vocabulary and conventions are necessary components of learning chemistry, out-of-class quizzes were used for the practice of this notional type of knowledge since this type of knowledge is widely available both in the textbook and on the Internet.

Inquiry Laboratory Experiences

The Science Writing Heuristic was used as a model for the students' laboratory investigations. This method helps students organize their thoughts and stay on track when answering scientific questions using an open-ended inquiry method (Greenbowe & Hand, 2005; Rudd et al, 2007). Greenbowe and Hand (2005) believe that "having students explain what they know in different ways" helps students construct a more integrated and "richer understanding of science." Thus, while students should be able to choose the correct answer in a multiple choice question or fill in a blank, they should also be trained in both speaking about what they have learned (in group situations and class discussions) and in writing about what they have learned as a means of garnering a thorough understanding of scientific concepts. Learning requires students to absorb information through their senses, which is disassembled and stored in different parts of the brain. Writing and speaking about science makes students reassemble their thoughts into coherent sentences, strengthening the link between ideas. Multiple choice and fill-in-the-blank questions can be answered with a lower level of understanding because students may use the process of elimination or give vague answers so as to not chance being incorrect by giving too much detail. In this way, students may trick teachers into believing that students understand concepts simply because they are able to answer some questions correctly.

The write-up for each lab was to be organized into ten parts (described in table 2). Students were required to purchase a laboratory notebook record all experiments in this format.

Table 2

Laboratory Format

1. Question to be answered
2. Pre-conceived notions
3. Hypothesis
4. Materials
5. Experimental Methods
6. Observations
7. Data Tables/ Graphs
8. Results
9. Conclusion
10. Post-lab questions

Labs were organized in a progressive manner and were designed to build on one another as shown in the outline described in the methodology. The scientific method was the first topic covered in the class. Although the majority of K-12 science textbooks begin with a rendition of the scientific method, after the chapter is completed, the method is out of sight and mind. In this class, students were required to evaluate concepts using the scientific method throughout the course using the template described in table 2. It is important for both science majors and non-science majors to understand the nature of scientific inquiry because the process is also a good method for everyday problem-solving. The method is systematic, thus efficient, and is based completely on logic not emotion. If students learn to recognize logical fallacies in their science arguments, then they are more likely to recognize illogical thinking during all kinds of reasoning, and without significant exposure to the scientific method, students are likely to label the relationship between two variables as cause-and-effect after one mere test. Superficial investigation and prematurely drawing conclusions allows students to shape their observations to fit their pre-conceived notions, whether they are misconceptions or correct notions.

Animations and Videos

Animations and videos were used to help students visualize chemistry at the molecular level nature of chemistry and to emphasize the relationship of chemistry to the world through current events. Molecular-level animations created by John Gelder, Michael Abraham, and Kirk Haines (2002) were used to demonstrate the relationship between individual particles of gas and the macroscopic observation of pressure as well as to simulate a chemical reaction on the molecular level. Animations from the Molecular Workbench project (at http://workbench.concord.org) were used to show students the difference between solids, liquids, and gases at the molecular level and to demonstrate how intermolecular forces act on the molecular level (Tinker, R., Berenfeld, B., 2007).

In-Class Demonstrations

Whenever scientific concepts could be macroscopically visualized, but resources or safety did not allow for the students to experiment directly, demonstrations were performed by the instructor. For instance, when discussing intermolecular forces and the relative melting points and boiling points of various substances, students performed experiments with a variety of different elements and compounds, but the instructor demonstrated the extremely low boiling points of liquid nitrogen and solid carbon dioxide. This allowed the instructor to show students some fascinating chemical phenomena that demonstrated how the nature of substances, their type of intermolecular forces, and the temperature cause various substances to behave differently, without putting students in unnecessary risk.

Traditional Exams

One method of student assessment was traditional exams in which students were given a variety of questions (multiple-choice, short answer, fill-in-the-blank, and show calculations). This method of assessment is good for determining a student’s ability to perform algorithmic calculations and apply concepts covered in class to word problems. There were three traditional exams during the semester worth 50 points each. Copies of the exams are provided in appendix B. It was predicted that type 1 students would perform better on traditional tests than on non-traditional, alternative assessments.

Out-of-Class Strategies

Weekly Quizzes

Weekly multiple-choice quizzes were administered through the class web site. The quizzes were automatically graded and saved to a database. Quizzes were designed to reinforce concepts covered in class, to rehearse students in the fundamentals of chemical symbolism, and to encourage students to think about the concepts outside the lab. Quizzes were also designed to be formative assessments. Formative assessments are not used to assess what has previously been learned but to serve as a learning experience for the students. Therefore, the students were allowed to take the quizzes as many times as they wanted to achieve the grade they wanted and to not limit the amount of learning from the quiz. Since the goal of the quizzes was to urge students to look up answers to their questions in the textbook, the more times students took the quiz, the more material they mastered out of class. This type of formative assessment gives students a quick and easy way to use repetition to learn the memorization aspects of chemistry and to follow up on concepts covered in the laboratory.

Ten quiz questions were randomly chosen from a bank of over thirty questions so that when students took the quiz a second and third time, they received a random set of questions relating to the overall theme of the quiz. Quiz questions were intentionally related to substances that students encounter in everyday life so students could make associations between macroscopic observations of chemicals and the particulate nature of chemicals in the context of concepts covered in class. The effort to make chemistry more familiar to students has shown positive results in learning outcomes and in student motivation (Gabel, 1999).

Alternative Assessments

The second method of assessment was called the “alternative assessments.” The alternative assessments urged students to apply information learned in class in new contexts and especially to explain everyday phenomena related to chemistry issues of public concern. According to the constructivist view of learning, it was assumed that students will be more likely to store information in long-term memory if the information can be related to or builds upon information that is already in long-term memory from everyday life or the news. Associating chemistry with everyday life presents a more accurate depiction of the complexity of chemistry, as opposed to creating separate mental constructs—one for chemistry and another for everyday life. The students worked on their alternative assessments outside class and had access to any resources they could find (except classmates). The questions were open-ended, so there was not a threat of students working together and turning in similar work. Three alternative assessments were assigned during the semester, and each assessment was worth 50 points. Topics of the alternative assessments were:

- General chemistry history and the making of the periodic table of elements
- How the relationship between diffusion and molecular weight helped the Allies build the first atomic bomb
- The ability or lack thereof of different compounds to dissolve in blood (glucose, cholesterol, aspartame) as a result of molecular structure and chemical make-up
- The differences in boiling points or melting points of common substances; developing experimental procedures to determine the relationship between two variables
- The fluoridation of public drinking water
- The relationship between the specific heat of a substance and the relative rate of temperature increase of substances.
- The classification of common forms of energy (kinetic, potential, chemical, radiant)

The alternative assessments are in appendix B.

Text

The textbook was not followed chapter by chapter. The purpose of the textbook was to be a reference for students to turn to for additional reading and pictures of concepts covered in class and as a source of extra practice problems. The textbook used for the class was like many general chemistry textbooks; it was, as many educators say, “a mile wide and an inch deep,” meaning that many concepts are briefly covered, but no concepts are covered in depth.

Grading System

Table 3

Course Grading Scheme

Category	Total Points Available	Percent of Grade
Experiments	260	32%
Traditional Exams	150	18%
Alternative Assessments	150	18%
Quizzes	120	14%
Final Exam	100	12%
Lab Technique / Participation	50	6%

The course grading scheme was designed to be most weighted towards experimental work, but the rest of the points were broadly distributed among 5 other categories. The broad distribution of points allowed for students to have many smaller opportunities to acquire points, rather than few large assessments with heightened consequences. This technique also encourages students to continually participate in the class and gives students many opportunities to obtain feedback on their work and understanding of concepts.

Data Collection

Data collection began on the first day of class and ended on the last day. The instructor collected various forms of information in order to assemble a complete representation of the course. The sources of data were the quantitative results of concept pre- and post-tests, qualitative observations from the instructor's journal, a survey of students' educational background, a survey of students' views of education, and students' responses to course and instructor end-of-semester evaluations.

One the first day of class, students completed a twenty-two question inventory concerning chemical concepts such as conservation of mass, phase changes, physical and chemical changes, the particulate nature of matter, models of the particulate nature of matter, buoyancy, density, concentration, solubility, the law of definite proportions, and heat capacity. The inventory was written by Mulford and Robinson (2002) and produced by the American Chemical Society. Students completed the same inventory on the last day of class. The purpose of the inventory was to assess the effectiveness of the course. See appendix A for the inventory.

The instructor kept a course journal to record qualitative data pertaining to instructor perception of educational strategies and effectiveness of techniques, student attitude towards specific educational techniques, apparent student motivation, time frames associated with specific projects, and any other interesting observations. This journal serves as the most detailed account of the study. Throughout the semester, the instructor kept observations of the students' behavior and problem-solving techniques in class in order to determine whether students tended to be field-independent (type I) or field-dependent (type II), the two overarching, value-laden learning styles described in chapter 3. It was hypothesized that students who exhibited field independence would have more success in the authentic class structure than students who exhibit field dependence.

On the first day of the course, students were given surveys in order to collect information about their educational background and goals for the class. Surveys were given to the students during the middle of the semester in order to evaluate students' views of education, students' preferences for learning techniques, and students' view intelligence and creativity. The purpose of this survey was to determine if a correlation existed between students' views and their performance in the authentic class. See appendix B for these surveys. Another student survey consisted of course/instructor evaluations, mandated by the University. This evaluation gathered information concerning instructor performance, grading techniques, and appropriateness of content and workload. This evaluation of the course served to collect students' opinions of the class and general attitude towards the class. The instructor until did not see the evaluations after the final grades have been reported, so students are most likely to be candid in this survey.

CHAPTER VI

EXPERIMENTAL DATA

Level of Field-Independence

Students' level of field independence was quantitatively determined by both the students' answers to a questionnaire and by the instructor's qualitative observations of students in class. A 1-3 scale was used to differentiate various levels of field-dependence/independence, with 3 representing the most field-independent. The score found via the questionnaire was averaged with the score provided by the instructor to obtain the perceived level of field-dependence-independence in table 4. The field dependence/independence questionnaire is provided in appendix B.

Table 4

Perceived Level of Field-Independence (Type I Intellectual Style)

Student #	1	2	3	4	5	6	7	8	9	10	11	12	13
Level of Field Independence	1.5	1.6	3.0	1.5	1.4	2.0	1.2	2.0	1.0	2.0	3.0	2.0	2.5

1 = field-dependent   3 = field-independent

Previous Coursework

Students' previous course work in science and math were recorded to determine whether a significant correlation existed between previous coursework and performance in the student-centered chemistry class (table 5). If student performance is directly proportional to previous course work, it will be unclear if the hypothesis-- that the student-centered class differentiates type I individuals from type II individuals-- is supported because of overlapping variables. However, if the previous number of science and/or math classes is not correlated to higher levels of field-independence and success in the student-centered class, the results will be more robust.

Table 5

Student History of Science and Math Education

Student #	High School Chemistry Courses	High School Science Courses	College Science Courses	College Level Math Completed
1	0	3	1	1
2	0	3	1	2
3	1	4	0	1
4	1	3	0	0
5	1	3	0	0
6	1	3	1	1
7	0	1	0	1
8	1	4	0	0
9	0	3	0	1
10	1	3	2	2
11	2	4	3	2
12	1	3	2	3
13	1	5	0	1

No students had previously taken a college level chemistry class.

Concept Inventory

The multiple-choice concept inventories (Mulford & Robinson, 2002) taken on the first and last days of class were evaluated and the questions were categorized by concept. Table 6 lists each student's initial concept inventory (ICI) performance (percentage correct) by concept, each student's overall average, and the overall average of the class. Information for the final concept inventory (FCI) is provided in table 7.

Table 6

Demonstration of Knowledge on Initial Concept Inventory.

Std.	Conserv of Mass	Phase Change	Temp . vs. Heat	Nature of Chemical Rxn	Buoy.	Concentr	Atomic Level Prop.	Total Percent Correct
1	37.5	0	0	33.3	0	33.3	33.3	27.0
2	12.5	0	0	66.6	0	33.3	33.3	23.0
3	75.0	0	0	33.3	0	33.3	0	36.0
4	37.5	0	0	0	0	33.3	0	18.0
5	25.0	0	50.0	100	100	66.6	0	45.0
6	62.5	0	0	0	0	66.6	0	27.0
7	25.0	33.3	0	0	0	0	33.3	18.0
8	50.0	0	50.0	33.3	100	33.3	0	41.0
9	37.5	0	50.0	0	100	33.3	66.6	41.0
10	25.0	33.3	50.0	0	100	66.6	33.3	41.0
11	12.5	33.3	0	0	0	66.6	33.3	23.0
12	12.5	0	50	33.3	0	33.3	33.3	23.0
13	50.0	33.3	0	0	0	66.6	0	32.0
Ave	35.5	10.2	19.2	23.1	30.0	43.5	20.5	30.4

Table 7

Demonstration of Knowledge on Final Concept Inventory.

	Conserv. of Mass	Phase Change	Temp Vs. Heat	Nature of Chemical Rxn	Buoy.	Concent.	Atomic Level Prop.	Total Percent Correct
1	50.0	0	0	0	0	33.3	0	27.0
2	62.5	0	0	33.3	100	66.6	0	45.0
3	87.5	33.3	0	33.3	100	33.3	33.3	59.0
4	87.5	0	0	33.3	100	66.6	33.3	59.0
5	25.0	0	0	0	0	33.3	33.3	18.0
6	100	0	50.0	66.6	100	66.6	33.3	73.0
7	62.5	33.3	0	33.3	50.0	33.3	66.6	50.0
8	50.0	0	100	66.6	100	33.3	33.3	55.0
9	62.5	0	0	33.3	0	33.3	33.3	36.0
10	100	33.3	0	33.3	100	33.3	0	59.0
11	100	33.3	0	33.3	50.0	66.6	0	59.0
12	75.0	0	50.0	33.3	0	0	0	36.0
13	75.0	33.3	0	0	100	33.3	0	45.0
Ave.	72.1	12.8	15.4	30.7	61.5	41.0	20.5	48.0

Graded Performance

Student performance in the class, measured by points earned divided by points possible, are shown in table 8. Students' grades are also broken down into each category of the grading scheme. The ICIs and FCIs were not graded assignments, but the scores are included in the overall class performance table for comparison. Percent increase on each student's concept inventory score is also provided (table 8)

Table 8

Performance in Class by Percentage

Student #	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
Overall Course Grade	79	73	92	82	81	95	77	81	67	90	99	82	80	82.7
Quiz	84	59	100	88	100	94	94	81	71	90	100	88	86	87
Alternative Assessment	78	73	95	85	76	94	70	72	65	90	96	77	76	80.5
Traditional Exam	67	68	96	66	66	100	61	75	54	80	100	75	74	75.5
Lab	87	76	83	91	86	98	82	88	80	94	97	86	74	85.5
ICI	27	23	36	18	45	27	18	41	41	41	23	23	32	30
FCI	27	45	59	59	18	73	50	55	36	59	59	36	45	48
CI Percent Increase	0	95	64	228	-60	170	178	34	-12	44	157	57	41	

Student Course Evaluations

It is important to gauge students' attitudes towards classroom methods; several studies have found that learning science has been positively correlated to good attitudes towards participating in science activities (Russell & French, 2001). Near the end of the course, an anonymous course evaluation was given to students in order to ascertain the students' appraisal of the instructor and the course. Table 9 and table 10 detail the percentage of students submitting various judgments of the instructor and the course, respectively. In the far right column, the average evaluation (out of 5 points) is shown for each category. In the bottom right corner of the table, the average instructor appraisal and the average appraisal of the course are shown, found by averaging the average scores of all the categories.

Table 9

End of Course Instructor Evaluation

Instructor Evaluations	Very High (5)	High(4)	Average(3)	Low(2)	Very Low(1)	Average Score out of 5
Preparation and Organization	7.6%	15.4%	69.2%	7.6%	0%	3.224
Teaching Effort	30.8%	15.4%	30.8%	23.1%	0%	3.542
Presentation of Material	0%	15.4%	46.1%	38.5%	0%	2.769
Knowledge of Subject	7.6%	61.5%	30.7%	0%	0%	3.761
Explanation of Subject	0%	15.4%	38.5%	46.1%	0%	2.693
Positive Attitude Toward Students	30.8%	53.8%	15.4%	0%	0%	4.154
Overall Instructor Performance	0%	30.8%	38.5%	23.1%	7.6%	2.925
Average 1-5 Scale Scores						3.29

Table 10

End of Semester Course Evaluation

Class Evaluations	Definitely Yes (5)	Yes (4)	Not Applicable (3)	No (2)	Definitely No (1)	Average Score out of 5
I learned a lot	0%	53.8%	15.4%	23.1%	7.6%	3.152
Workload Appropriate	0%	23.1%	0%	30.8%	46.1%	2.001
Assignments Useful	0%	69.2%	15.4%	15.4%	0%	3.538
Good Evaluations	0%	46.1%	15.4%	38.4%	0%	3.074
Involved Students	30.8%	53.8	15.4%	0%	0%	4.154
Worthwhile	0%	23.1%	7.6%	30.7%	38.4%	2.150
Overall, good Course	0%	38.4%	7.6%	46.1%	7.6%	2.762
Average 1-5 Scale Score						2.968

CHAPTER VII

RESULTS AND DISCUSSION

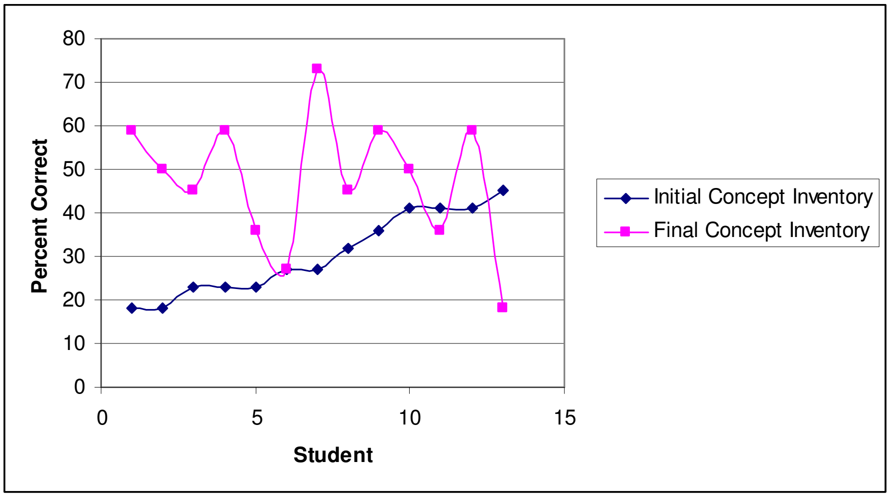
Results

Concept Inventory Performance Results

Initially, students correctly answered questions on the concept inventory an average of 30% of the time. At the end of the semester, students correctly answered questions on the concept inventory an average of 48% of the time, a 60% increase. Unfortunately, the data may not entirely represent true achievement of all students; it was found that the student who scored the highest grade on the initial concept inventory (ICI) also scored the lowest grade on the final concept inventory (FCI). Based on the instructor's evaluation, the student did not try their best to accurately report their knowledge on the last day of class, perhaps because the inventory was not a graded assignment. All other students' scores appeared to be accurate portrayals of their knowledge on both inventories. Omitting the outlying score on the FCI, the overall average class performance on the ICI was 29% and the FCI average score was 50%. This would be a 72% increase in conceptual understanding of chemistry. For the rest of the analysis, student 5 will be omitted from concept inventory statistics.

Figure 1

Individual Student Initial and Final Concept Inventory Score

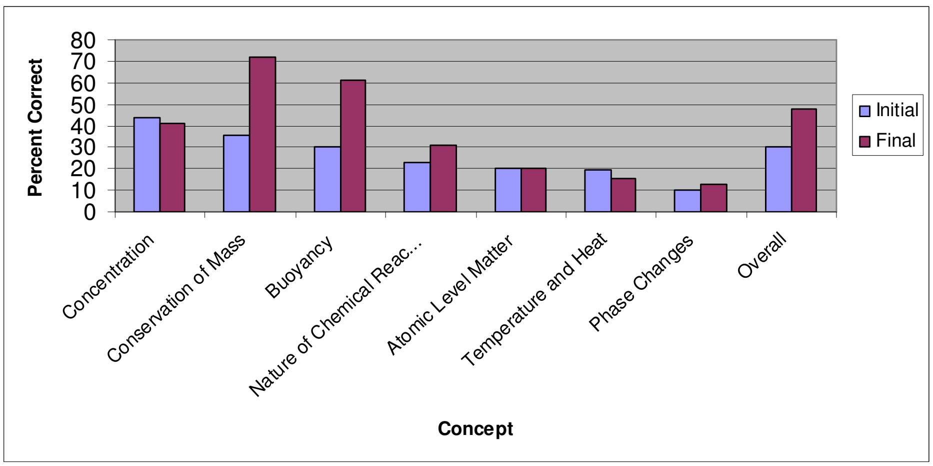


No relationship was found between a student's score on the ICI and their score on the FCI (r= .265, α = .05) (figure 1). There was also no significant correlation found between number of high school chemistry credits earned and ICI score (r=.075, α= .05), number of high school science credits and ICI score (r=.349, α=.05), number of college science credits and ICI score (r=.259, α=.05), or number of college math credits and ICI score (r=.310 α=.05). Additionally, there were no correlations between a student's score on the FCI and the number of high school chemistry credits(r=.4028, α=.05), the number of high school science credits (r=.1157, α=.05), the number of college science credits (r=.1845, α=.05), or the number of college math credits (r=..0452, α=.05). These findings negate the possibility that prior knowledge was an important variable in predicting performance either on the ICI or the FCI, and that a student's score on the FCI is a consequence of the class and not of previous science knowledge.

Students were most unfamiliar with the concepts of phase change, heat and temperature, and the atomic nature of matter on both the ICI and on the FCI. Despite the course's heavy emphasis on physical changes as opposed to chemical changes, students were most likely to miss questions relating to phase change on both the ICI and FCI, with only a slight improvement on the FCI (figure 2). The atomic nature of matter was also emphasized in the course, and this concept was third most likely to be missed. Further, there was no improvement on the concept of the atomic nature of the atom from initial inventory to final inventory (figure 2).

Figure 2

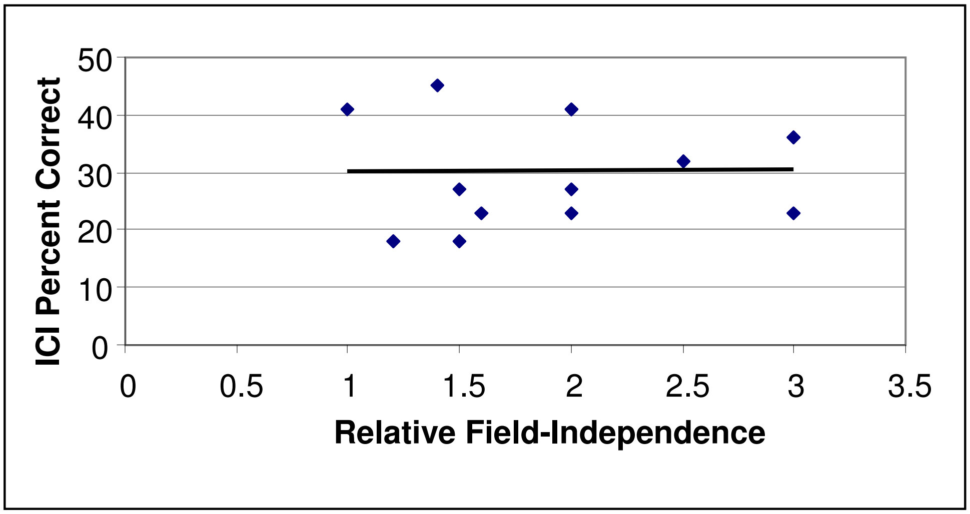
Initial and Final Concept Inventory Performance



The level of a student's field-independence had no correlation to performance on the ICI (figure 3). If students' previous science knowledge is in no way related to a students' intellectual style, this may be an indication that, in general, students' prior science understanding is not a result of their style of learning. This supports the hypothesis that traditional high school and college science classes do not result in long term learning and do not rely on methods that promote field-independent thinking. In fact, the three highest scores on the ICI were from students with relatively lower levels of field independence suggesting that students who are more adept at memorizing information came into the class knowing more than students with a field-independent intellectual style.

Figure 3

Initial Concept Inventory vs. Relative Field-Independence



The relationship between FCI score and level of field independence is also not statistically significant (r = .156). The highest scores on the FCI ranged from students of all levels of field-independence (figure 4), indicating that the format of the class does not hinder the learning of students with lower levels of field independence. In this way, students are rewarded for field-independent behavior in class through their grades, but students who may prefer a field-dependent class structure were still able to learn concepts either by the field-independent activities, the text book, the quizzes, or the short lectures and discussions. In fact, students with an intermediate level of field-independence (Type III style) had the highest scores on the FCI. Perhaps an intermediate level of field-independence allows students to learn from independent activities as well as from lectures and the textbook. Students with lower levels of field independence were also just as likely to increase their performance on the CI over the course of the semester as students with higher levels of field-independence were. The 4 students with the largest increases in CI spanned the whole field-dependence/independence scale (figure 5).

Figure 4

Final Concept Inventory Score vs Relative Field Independence

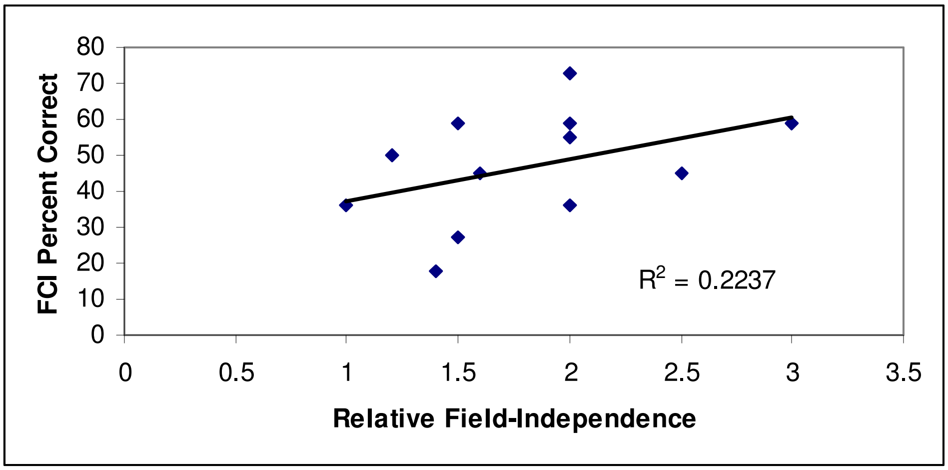
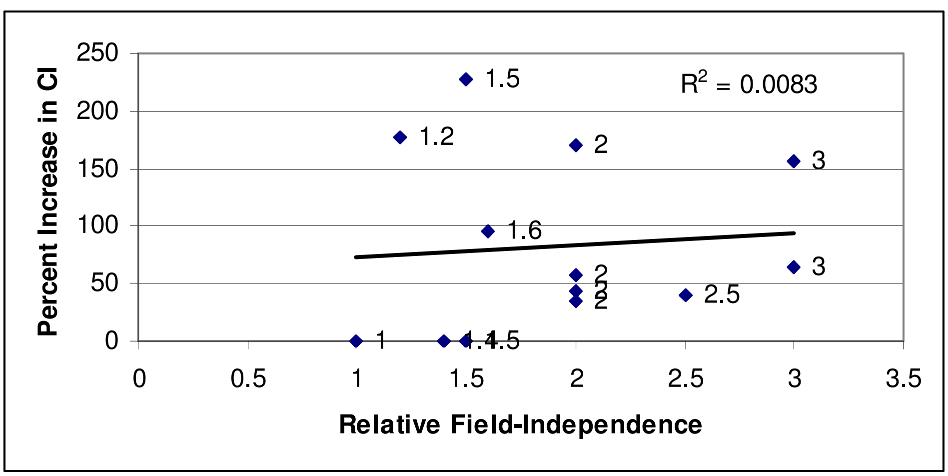


Figure 5

Percent Increase in CI vs. Relative Level of Field-Independence

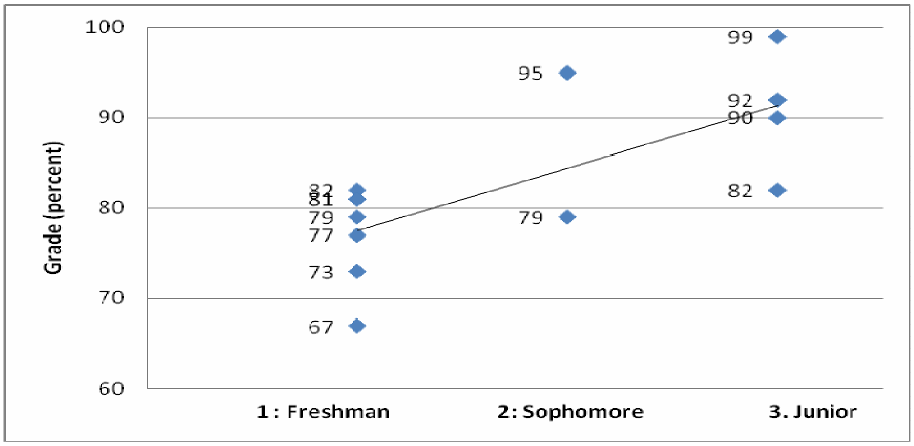


Class Assessment Results

High performance in this class was found to be correlated to several variables. As figure 6 shows, school level was a major predictor of success in the student-centered

Figure 6

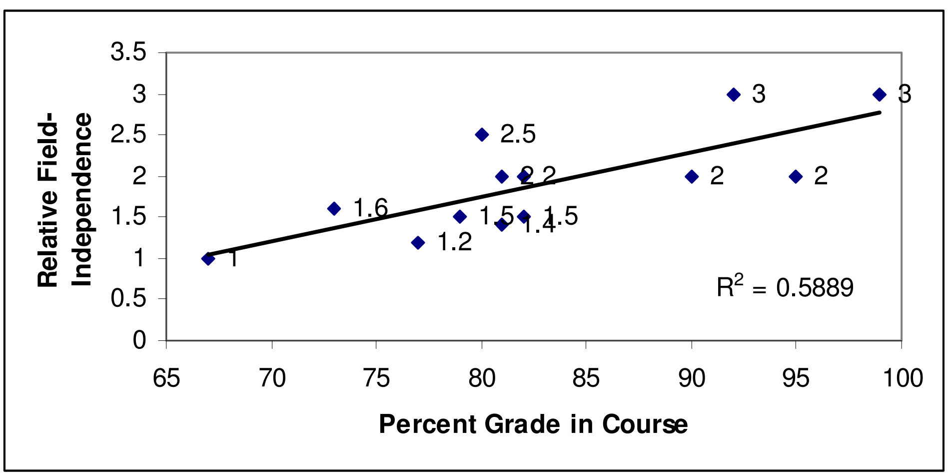
Grade in Course vs. School Level



classroom. This is not a surprising result as these students most likely have some level of experience in self-guided learning as a result of their college courses. They have also had more time to develop effective study habits.

Figure 7

Percent Course Grade vs. Relative Field-Independence



A statistically significant, positive correlation (r = .675, α = .05) was found between the observed (figure 7) level of field independence and overall grade in the course. This was expected because people with field independence (type I intellectual style) adapt more readily to new situations and are, in general, more independent. This finding provides some support for the hypothesis that field-independent students will perform better in a student-centered environment and suggests that the student-centered class grading-scheme differentiated type I students from type II students.

Concept Inventory and Class Assessment Results

Students that earned an 'A' in the course increased their CI score by an average of 30.75 points. Students that earned a 'B' in the course increased their CI score by an average of 10.8 points (if the one outlier is rejected from the data set, 'B' students increased their CI score by an average of 20.25 points). Students that earned a 'C' in the course increased their CI score by an average of 18.0 points, and students earning a 'D' in the course decreased their CI score by an average of 5 points.

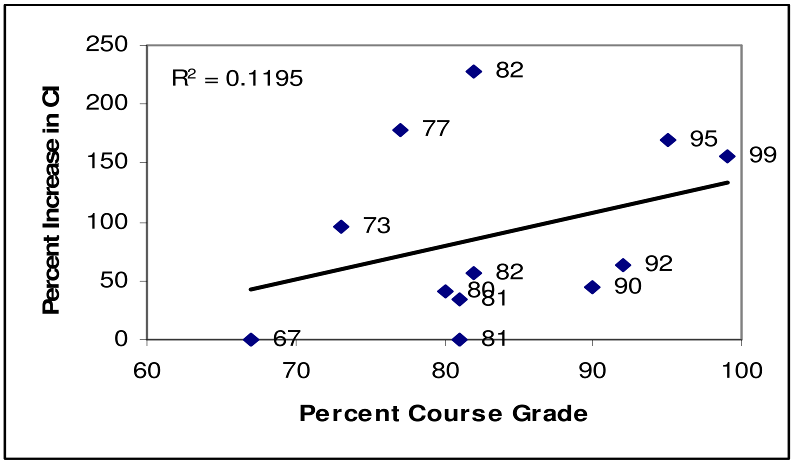
Percent increase on the concept inventory was not significantly correlated to overall class grade. Figure 8 shows this weak relationship. This is another piece of evidence that suggests although the grading format of the class differentiated type I students from type II students; this did not inhibit type II students from learning in the student-centered environment, and type II students were also able to increase their concept inventory scores by a substantial amount.

Student Attitudinal Results

Overall, the students evaluated the instructor and the class methodology as average. On a scale from one to five (five being the highest approval) tables 8 and 9 show that student responses were widely varied, and usually averaged to around 3. Students were least satisfied with the instructor's presentation of material and ability to explain subject matter but were most satisfied with the instructor's attitude toward students. Over half of students reported feeling least satisfied with the appropriateness of the work load for the amount of credit hours awarded.

Figure 8

Percent Course Grade vs. Percent Increase in CI



Ironically, 68% of students reported that the class was not worthwhile to them while over half of the students reported that they had "learned a lot" in the course. One of the instructor's main goals for the class was to make it student-centered, and 85% of students reported that they were adequately involved (15% did not answer the questions, and no students reported being uninvolved).

Discussion

Goals

One main goal of the project was to answer the question, "Can an inexperienced teacher use student-centered methods to effectively teach the abstract subject of chemistry to non-science majors?" It is assumed that effective learning is evident if students' behavior reflects increased conceptual knowledge due to the course (and not to previous courses) on questions that students have not rehearsed. Additionally, the project sought to answer other questions teachers may have regarding student-centered or inquiry-based teaching strategies such as "What student characteristics correspond with success in a student-centered classroom?" "What challenges are presented in a student-centered class?" and "What are student views of a student-centered class?"

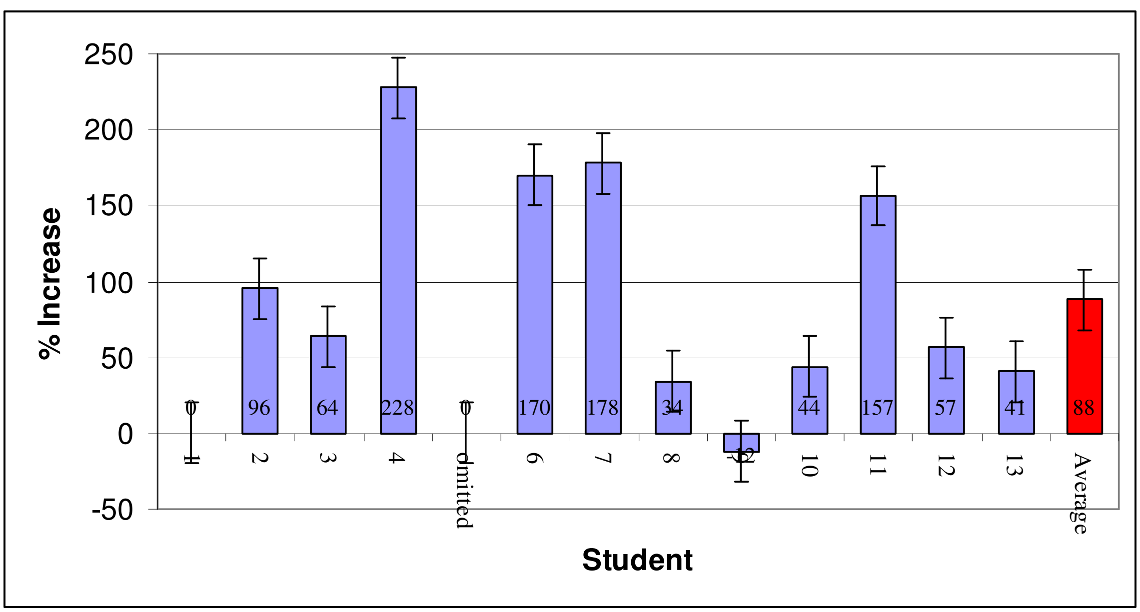
The majority of current literature suggests that using student-centered methods in science education is better than traditional methods provided that students receive ample feedback as they work. However, most Americans grew up in an educational system that employed traditional lecture methods and the transition to practicing authentic learning may not come naturally in the formal school setting. But, as the U.S. participates in the ever more competitive global economy, it is necessary to ensure that science education follows a course that is conducive to economic success. This type of education—education that encourages students to think for themselves-- will enable students to be questioners, innovators, and group collaborators. In order to produce students with these attributes, the students must learn these processes in the educational setting. In the information age where information is readily available, perhaps these behaviors are more important than a large knowledge base.

A conceptual pre- and post-test created by Doug Mulford (2002) and published by the *Journal of Chemical Education* was the primary means of measuring the effectiveness of the course. Students were not directly instructed to the test, but the test covered concepts investigated by students through inquiry laboratories. Concepts covered included conservation of mass, characteristics of matter (density and buoyancy), physical changes (phase change solubility, and concentration), chemical changes (reactions), the particulate nature of matter, and the energy-matter relationship.

The average score of the class rose from 29% correct to 50% correct on the concept inventory. This was a 72% increase. Individually, the average percent increase of each student was 87.87%, with a standard error of 22.23% (figure9). When this concept inventory was given to 1400 students before and after a Purdue chemistry class for science and engineering majors the average pre-semester score was 45% and the average post-semester score was 50%, an 11% increase (Mulford & Robinson, 2002). All of the students in the Purdue chemistry class had taken high school chemistry, whereas 70% of the students in this study took a chemistry class in high school. This variance could account for the overall higher scores of the Purdue students, but the students at Oklahoma State University saw a greater learning increase in a student-centered environment. Therefore, it is concluded that student-centered techniques can be an effective method for teaching abstract concepts such as those in chemistry.

Figure 9

Percent Increase in Concept Inventory Score



Standard Error = 22.23

Experiments

Collectively, the experiments were successful fulfilling the goals presented in table 3 —that students will form testable hypotheses, develop experimental procedures, recognize patterns and trends, organize data into tables, explain evidence, and use evidence to argue the validity of a statement. Each student's lab notebook demonstrated all of these behaviors at some point during the semester. At the beginning of the semester, most students tried to design confounded experiments with three or more variables or more than one hypothesis. Through in-class feedback all students saw that data were much easier to interpret when only one factor is varied at a time. Through one-on-one discussions, the instructor is certain that the course led all students to appreciate the systematic design of an experiment with one hypothesis, one independent variable, one dependent variable, and an attempt to control all other variables.

Quizzes

The intended effect of the quizzes was not realized for all students. Some students said that they stopped trying after they achieved a relatively high grade (70-80%), because they worried that if they took the quiz again, they would not be able to make as high of a grade. This behavior differentiates students who think that they can understand chemistry if they try hard enough from the students who think that their grade on the quiz was a fluke and that there is no way they will ever be able to achieve another high score. The former set of students hurt themselves by not taking the quiz as many times as they could until they knew the answers to every question. This problem may have been ameliorated to some extent if the instructor had taken the highest score for each quiz rather than the last score earned in determining the grade. The number of times students participated in the quiz each week was found to be positively correlated to success in the class. However, this correlation could have occurred for several reasons: students who try hard on the quizzes may be, in general, more motivated to spend time learning and studying; or the repetition involved in taking quizzes many times may cause strong neural connections to evolve and hence learning to occur. It is likely that both these reasons are somewhat related to success in the class.

Assessments Methods

Students tended to perform better on the alternative assessments (AAs) than on the traditional tests (TTs). The average AA score was 80.5 % while the average TT score was 75.5%. The difference can most likely be attributed to the fact that students are put on the spot during a TT, but have more time and resources to answer AA questions. However, questions on the AAs were more thought-provoking and considerably more complex that questions on TTs. Students reported spending more time on AAs and were appreciative of the extra time they had to complete the work. The instructor was satisfied with the students' performance on the AAs and felt that AAs were more effective at differentiating students according to the degree of concept understanding. The open-ended questioning allowed students to demonstrate the extent of their knowledge and virtually eliminated "guessing" as a means of passing the test. Due to the small class size, identical or similar answers were easy to identify, which deterred students from sharing work outside of class. This type of evaluation is appropriate for small classes, but would be difficult to grade and monitor for individual work in a larger class.

Student Attitudes

The goal to design the class to be student-centered was achieved, but the class was perceived to be too much work and not worthwhile for more than half of the students. A possible reason for the sub-par evaluation of the instructor's presentation and explanation of material could be due to the common practice in the class of: a) forming groups, b) making observations or doing hands on research in order to make a hypothesis, c) testing the hypothesis, d) coming to independent conclusions, and e) discussing every groups findings as a class. All of this came before the instructor emphasized the main points, demonstrated calculations, and expanded on lab results and the earlier discussion. The instructor did the organized presenting and explaining after the open lab time, but also did a lot of one-on-one (teacher-on-group) brainstorming with, explaining to, and guiding of student groups during the open lab time. The students could be referring to this non-organized, student- teacher interaction time as being less than satisfactory; perhaps students felt that the instructor spent more time with certain groups or was not fair in giving helping hints and suggestions. This area appears to be the biggest down fall of the inexperienced teacher, and it is unknown if students would have given the same evaluation had the instructor given traditional lectures. One factor that differentiates the type of presentation and explaining that occurs in a traditional classroom from the type displayed in this classroom is that prepared lectures can be rehearsed and performed, whereas discussions in this classroom were dependent upon student results, student questions, availability of time, and were on the whole, much more unpredictable. This aspect of the class makes the instructor's job unpredictable, and experience is the best tool for this situation.

Limitations

Limitations of this study stem from the small size of the class (n=13), the absence of the male gender in the class, and the lack of an experimental control group. Thus, the project is a qualitative case study of techniques that will be useful for educators for background information, ideas, and motivation regarding student-centered classroom practices. Further research yet to be performed includes testing developed curriculum and techniques in larger class settings, in high-school class settings, among low achieving students, among high achieving students, and over multiple semesters.

CHAPTER VIII

CONCLUSION

Are student-centered educational techniques effective for abstract subjects?

The percent increase in students' before and after concept inventory scores leads to the conclusion that student-centered methods are effective for teaching chemistry, at least in a small classroom environment. The students' average initial concept inventory score increased by 72% over the course of the semester while Purdue students in a traditional chemistry class only increased their scores by 11%, but the fact that the student-centered class was much smaller than the chemistry class at Purdue leaves the possibility that the larger increase in concept inventory score could be due to the more individual attention that students receive in a small class setting. In order to repeat these results in a large classroom, students may need more individual attention than they would receive in a traditional large lecture class. As technology improves, student feedback could be electronically mediated and the general concept of student-centered learning could be adapted for a large class size.

Although student-centered environments, small class sizes, and group work may help to motivate students, intrinsic motivation has been found to be the most important predictor of success in any classroom. It has been found that motivation to learn a concept is inversely related to the abstractness of that concept (Jurisevic et al., 2008).

Chemistry is one of the more abstract sciences, so motivating students is a challenge for chemistry teachers in particular. It has also been concluded that motivation and perceived level of control are directly related (Dweck & Leggett, 1988). Therefore it is assumed that the more control students have over their learning of an abstract subject, the more motivated they will be to learn. It is concluded that student-centered methodology is effective in teaching the abstract concepts of chemistry.

What concepts are particularly suited for inquiry-learning?

Concepts explaining everyday chemical phenomena are easily adapted to an inquiry learning environment because students have some ideas about the concept before they design and perform an experiment. Although students may be familiar with an everyday chemical concept, they have probably not asked themselves why or how the phenomenon happens. Knowing some background information helps students form hypotheses about the why or how a chemical phenomenon occurs. Also, when everyday chemical phenomena are used to demonstrate chemical concepts, the materials tend to be inexpensive, readily available, and not very hazardous.

On the final concept inventory, students made the most improvement answering questions correctly about conservation of mass and buoyancy. Both of these concepts are observable on the macroscopic level, so the students' hands-on involvement while studying these concepts may have had a greater impact on the students when compared to concepts like the atomic properties of matter, and temperature and heat.

The students, as a whole, performed worse on temperature and heat questions on the final concept inventory than on the initial concept inventory. While temperature and heat were not the focus of any laboratory experiences, the topic came up in regard to other labs such as the melting and boiling point lab and the releasing chemical potential energy lab. Students also performed poorly on concentration questions on the final concept inventory. Again, concentration was not the focus of any lab, but was discussed in the acid and base lab. The two areas in which students performed worse on the final concept inventory than they did on the initial concept inventory were temperature/heat and concentration. Since these topics were not stressed in the class, it is unknown whether these topics are not suited for inquiry-based labs or not. In the future, inquiry labs that focus on these two concepts could be devised and tested on students in order to determine if these topics are appropriate for inquiry-style investigations.

Can a novice teacher create a student-centered environment?

The inquiry-based, student-centered chemistry class taught by a novice instructor led to several conclusions. First, inexperienced teachers *can* create a student-centered environment in science education. The instructor teaching the class in this project had previously been a teacher's assistant for several years but had never created lesson plans, designed labs, or written quizzes and tests. From this perspective, the instructor was inexperienced. However, the instructor's goals (table 1, p. 67) for the class were realized, and the students as a whole were able to increase their knowledge of basic chemistry concepts by 72%.

Second, it will not be easy for a novice teacher to create a student-centered environment, especially if the teacher has not been educated in student-centered techniques. Finding resources for a student-centered class is more difficult than finding the resources for an expository class. The material for a student-centered class must present a situation which leads students to think (or act) without specifically telling the student what to do or stating a concept that the students should learn. Instead, resources and material need to be broad enough that students could come to a general conclusion through different paths and not so broad that students become off subject easily. The instructor also needs to be mindful of what he or she says when facilitating student-centered activities. The instructor must acquire a sense for determining which statements will help students to think for themselves and which statements will give the students too much information and jeopardize the students' chance to figure concepts out for themselves. From the perspective of the instructor in the course described in this project, it would have been unlikely that she would have been able to create a student-centered environment without the aid of her advisor, lots of books and journal articles, and a science education course (that taught inquiry methods).

What challenges does an inquiry-based environment present?

The most evident challenge to teaching an inquiry-based classroom was convincing students to make the transition from listening to lectures and taking notes to thinking for themselves and participating. At the beginning of the semester, students were uncomfortable making decisions about what they should do in class given a question to answer and some materials with which to answer the question. Some students would repeatedly say "I do not know what to do." With guidance, theses students were able to function in the class. It may be wise to gradually transition students into inquiry-based environment to prevent students from being overwhelmed at first.

Another challenge is the responsibility of teaching a class in which students are using chemicals to (partially) create their own experiments. The instructor was able to keep a close watch over students in the class because there were only 10 students, or 5 groups working at a time. In a larger class, this challenge could present a problem. Although a teacher can warn students about the dangers of the lab chemicals, and tell students “Do not do X,” there is no way to predict all the possible dangerous scenarios. For larger classes, a knowledgeable teacher aid would be a good idea so that students could be better monitored.

Does a student-centered classroom differentiate between students with type I intellectual styles and type II intellectual styles?

Based on the evidence that type I and type II students performed roughly the same on the multiple-choice final concept inventory, this study does not conclude that students with type I intellectual styles will learn more in a student-centered environment than type II students. However, students with type I intellectual styles were able to perform better on the tasks required of the class, which were largely group-oriented and/or independent projects. Additionally, type I students performed better on the class exams than type II students, and class exams were considerably more open-ended than the multiple-choice concept inventory. Therefore, this study concludes that student-centered classroom environments are not better or worse at preparing students for multiple-choice examinations, but that student-centered classrooms are inclined to lead students to become more independent with their work and differentiate students that are able to display type I learning behaviors.

In the inquiry-based class presented here, students with greater levels of field-independence received higher grades in the course but did not necessarily do better on the final concept inventory. This suggests that all students were able to learn enough from the class to answer multiple-choice questions correctly, regardless of intellectual style. The fact that student's who were more field-independent received higher grades in the class suggests that the type of assignments (labs, alternative assessments, out-of-class quizzes) were geared towards students with type I intellectual styles. Thus, the class rewarded students who were able to work more independently more than those (type II students) who relied more on lectures and explicit direction to facilitate their learning. Although the relative field-independence before and after the class was not measured, it is hypothesizes that type II students will eventually adapt to the course structure and become more like type I students. Most scientist's who study intellectual style agree that one's intellectual style is malleable (Zhang & Sternberg, 2006). Therefore, if type I intellectual styles are desirable to employers, it is worth the effort to mold students to think in such a way that will prepare and enable them to have a productive career in the one of the fastest growing job markets.

What are students' attitudes towards student-centered learning?

During the first few weeks of class, students were not familiar with student-centered learning and seemed uncomfortable with the idea. However, by the second half of the semester, the class as a whole was showing vast improvement in the ability to form a testable hypothesis without the help of the instructor. In retrospect, due to the instructor's notion that most students (specifically first semester freshman) were inexperienced at being asked to think independently in class, perhaps the class could have been more effective had the students been gradually transitioned into this type of learning environment. A more gradual transition may have led student to have better attitudes about the class and more self-confidence in their ability to control their learning. The instructor does believe that if these same students took another student-centered class, they would have an advantage over students unfamiliar with having a locus of control in the classroom. Once the initial challenge of motivating students to actively think for themselves is accomplished, the whole demeanor of the class changes and students are more comfortable with the environment.

The anonymous end-of-course evaluations showed that students were either pleased with the class or were not pleased with the class. On average, then, the instructor and the course received average ratings. Based on intellectual style, it is assumed that students with type I intellectual styles were happy with the course assignments and assessments, and those students who tend to favor a type II intellectual style most likely did not appreciate the open-ended assignments and alternative assessments. In fact, one student anonymously commented, "I had to teach myself everything."

Final Conclusions

The instructor of the class presented in this study was pleased with the overall results of the class. It was rewarding for her to see students progress from being unsure of how to write a testable hypothesis to being able to brainstorm multiple ideas about a scientific phenomenon and use those ideas to form a hypothesis. At the end of the semester, most students were showing proficiency at devising a non-confounded experiment (choosing only 1 dependent variable at a time). From these conclusions, the instructor has concluded that students learned the process of science and how to use the scientific method for problem solving.

Although she was initially disappointed with students' average final concept inventory score of 50%, once she compared this number to Purdue science majors' 50% average score, the score seemed to be reasonable. Remarkably, students in the inquiry-based class were able to improve their average concept inventory score by 72% while the Purdue class only increased their average concept inventory score by 5% through out the semester. While a 72% improvement is noteworthy, the fact that the students were unable to answer half of the questions correctly leaves a lot of room for improvement.

As a result of this project, the instructor of the course has gained valuable experience in the field of student-centered science education. By developing materials for the class, the instructor showed that it is possible for educators to research student-centered techniques and adapt this philosophy to his or her classroom (even in the absence of school system support in the form of money spent on new resources and teacher workshops). However, if school systems expect science to be taught by inquiry, then they should support educators with the proper resources to do so. The purpose of this project was to provide a case-study example for educators who are not familiar with student-centered methods and to answer questions that such teachers may have. By contributing experiences and material to the overall body of knowledge surrounding science teaching, the instructor hopes to motivate and convince teachers to try student-centered teaching methods at the classroom level as a means of improving science education in the United States as a whole.

More research on the potential benefits of student-centered learning needs to be undertaken in order to either substantiate or repudiate the claim that either students learn more deeply, or learn to think for themselves, or learn more concepts, or learn reasoning skills to a greater degree than students in a traditional lecture class. As any scientist should know, the more data that is collected, the more robust the conclusion. At this point, in 2008, while inquiry has been touted by psychologists/educational researchers and policy makers since the 1960s, there remains a substantial gap between educational research and professional practice (Korthagen, 2007). As with students, teachers' pre-conceived notions about the act of teaching are a powerful predictor of how a teacher will teach, regardless of published research (Stofflett & Stoddart, 1994). In order to bridge the gap between research and practice, teachers should be encouraged to conduct action research in their own classrooms (Korthagen, 2007). If student-centered learning is better than traditional education techniques, teachers will see this for themselves, much like how students in an inquiry class gain information from experiments that they perform in class. Since previous methods of improving science education by reporting the results of research on student-centered classrooms in journals and making inquiry learning a state mandated process standard have failed to have much effect, insider research may be a more effective means of integrating student-centered methods into teacher methodologies.

While the work presented in this study is informational, future research needs to be conducted in order to support or reject the specific conclusions made in this study. Future work includes testing the developed curriculum on larger and more diverse class populations, finding a more objective method of determining a student's intellectual style, and finding whether type I individuals are more valuable than type II individuals in a science-based work place.

The political and media spotlight on education will most likely continue to intensify while different groups will come to disparate conclusions concerning the same studies. However, if efforts were turned away from the mere outcome of standardized testing, accountability, and the U.S.'s international ranking, more efforts could be focused on improving education in the United States regardless of its current international ranking. Even if the US had the best international science and mathematic scores, it would be unwise to stop striving for increased excellence. One way to improve education for every student in the U.S. is to analyze scientific educational research in order to determine the best and most productive teaching strategies that will prepare students for the future. This will require the resources of all educators working collectively to continually improve education in the United States.

Rarely in the history of the world has the future not held a revolution of scientific ideas and technological advances. Thus, it would be practical to consider that the 21st century will bring understanding to once unfathomable ideas and great strides in scientific achievement. While it would be less sensible to guess the knowledge that the future will hold, it is necessary to prepare students for the unknown, ever challenging and evolving scientific and technological civilization. The commodities of the future will be information, knowledge, and problem-solving (Gabel, 1999). Science literacy will also become more and more necessary for citizens to be able to make well-informed decisions in their daily life and in their political positions. In an effort to best prepare students for the future, educators must decide and commit to a strategy that has the interest of the students, the economy, and the democracy in mind.

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APPENDIX A

INQUIRY LABORATORY EXPERIMENTS

A-1 Lab #1 Matter and the History of Chemical Discoveries

1. What is matter and what is it composed of?
2. What are some characteristics of matter?
3. What is the periodic table of elements?
4. What is a chemical reaction?

Matter is anything that occupies space.

Atoms are composed of protons, neutrons, and electrons.

A material that is made up of only 1 type of atom is called an element.

A compound is any substance that is composed of two or more elements.

Elements are listed on the periodic table in order of increasing atomic number (number of protons).

Each element has a different atomic symbol and atomic number.

A chemical reaction or a chemical change occurs when atoms in a substance are rearranged to give a new substance having a new chemical identity.

Question #1
Do elements combine in specific mass proportions to form compounds, or do elements combine in a random manner with unpredictable results? Provide an answer for this question based on experimental results.
Joseph Proust

Question #2
During a chemical reaction, can mass be created or destroyed, or is the total mass of the reactants equal to the total mass of the products? Support your answer with experimental data.
Antoine Lavoisier

Question #3
Do different types of atoms have different masses? Provided that equal volumes of gases contain equal numbers of atoms (or molecules), how can one logically answer this question and support it with experimental data?
Stanislao Canizzaro

Question #4
What are the structural features of an atom? What is an atom’s volume mostly composed of? Where are the subatomic particles found in an atom?
Ernest Rutherford

Question #5
Do subatomic particles carry a charge? How could one be reasonably sure of this?
J.J. Thompson
Robert Millikan

A-2 Lab #2 Atomic Structure and Periodic Trends

In order to become more familiar with the periodic table of elements, we will investigate trends some trends seen on the table. Since we do not have the equipment to measure atomic radii and atomic masses, we will use published values for our data.

Part 1
Question: How does atomic structure relate to the different average atomic masses of different elements?

Generate a hypothesis to describe the relationship between the varying atomic structures of atoms of different elements and the varying average atomic masses of different elements on the periodic table of elements.

A graph will be expected in the data/calculation section to help you either support or disprove your hypothesis. The graph will help you analyze your data.

(Reminder, *Results* is where you state the outcome of your experiment.
Conclusion is where you restate the hypothesis, whether it was supported or refuted by the results, and why you think the results came out as they did.)

Make sure your conclusion answers these questions:
Was your hypothesis supported or refuted? Were your results completely consistent with your hypothesis, or only partly? If so, why is this? If not, why not? What were some sources of possible error? Does your conclusion lead you to any further questions that could be tested?

Post Lab Question:
If ice cubes and liquid water are both made up of H_20, two atoms of hydrogen and one of oxygen per molecule, why does ice float on water? Use the terms atomic mass, density, volume, ice, and liquid water while thoroughly explaining your answer.

Part 2
Question: How does the structure of the atoms on the periodic table of elements relate to the sizes of atoms on the periodic table? (The size of the atoms can be estimated by the atomic radius).

Generate a hypothesis that will allow you to estimate the relative size of an atom on the periodic table. (Relative meaning in relation to each other, for instance, if I pointed to 2 different elements on the periodic table and asked "Which one is bigger?" how could you tell which one is larger based on its location on the table, not by comparing atomic radius data). Your hypothesis should predict whether atomic size will increase or decrease as one moves across a row, and as one moves down a group.

A graph will be expected in the data/calculation section as evidence to help you either support or disprove your hypothesis. The graph will help you analyze the data.

The following questions should be answered in your conclusion:
Was your hypothesis supported? What led you to guess your original hypothesis? Were your results completely consistent with your hypothesis? If so, why is this? If not, why not? What were some sources of possible error? Does your conclusion lead you to any further questions that could be tested? How do chemists explain the trend in size as one goes from left to right in the same row of the periodic table (this may require research in a book or internet)?

Post-Lab Question:

Define the term effective nuclear charge. How does effective nuclear charge affect atomic radii?

Part 3

A bond is an electromagnetic force that holds two atoms together, either in an element or a compound. Every electron is a small magnet, so the electromagnetic force that holds atoms together (attracts protons to electrons) can also attract two atoms to each other. In a **covalent bond**, one electron from each of the two different atoms is “shared” between the two nuclei. This means that a covalent bond consists of two electrons that are attracted to two different nuclei. An **ionic bond** is formed between two ions (charged atom), a cation (positive ion) and an anion (negative ion). Atoms become ions when they either lose electrons or gain electrons.

Electronegativity- a measurement of an atom’s ability to attract electrons to itself in a bond.

Question: How does the electronegativity of an atom relate to its atomic structure?

Generate a hypothesis that will explain the general trend of electronegativity as one moves from left to right on the periodic table of elements, and the trend of electronegativity as one moves down a group.

A graph will be expected in the data/calculation section as evidence to help you either support or disprove your hypothesis.

The following questions should be answered in your conclusion:
Was your hypothesis supported? What led you to guess your original hypothesis? Were your results completely consistent with your hypothesis? If so, why is this? If not, why not? What were some sources of possible error? Does your conclusion lead you to any further questions that could be tested?

Post-Lab Question:

In a covalent bond between hydrogen and oxygen, which atom will attract the bonding electrons closer to it?

A-3 Lab #3 Melting and Boiling Points

Question: Is the type of bonding a substance exhibits related to its melting and/or boiling point?

Melting Point- The temperature at which a substance melts (solid → liquid). The melting point of water is 0 degrees Celsius and 32 degrees Fahrenheit.

Boiling Point- The temperature at which a substance vaporizes (liquid → gas). Also, the boiling point of a substance is equal to the temperature at which the vapor pressure of the liquid equals the atmospheric pressure.

Lewis Structure- a molecular model of a covalent molecule including bonds and non-bonding electrons. The three-dimensional shape of the molecule is not conveyed.

Ionic Bond- an electrostatic attraction between a positively charged ion and a negatively charged ion.

Covalent Bond- a bond that forms between two atoms that are sharing one or more pair(s) of electrons.

Ionic compounds: substances that are formed with ionic bonding

Covalent compound (or element): substances that are formed with covalent bonding.

Your job is to make LOTS of careful observations of a variety of ionic and covalent substances and their chemical phases at room temperature and note their melting and/or boiling points. Based on your knowledge of common compounds and your observations, devise a hypothesis and a method to test your hypothesis quantitatively (in a measurable way, expressed with numbers and units).

Address the following questions in your conclusion:

What characteristics differentiate solids, liquids, and gases from each other on the atomic level? Molecular level pictures may help you explain.

Explain how the temperature can affect a substance's phase on the molecular level.

Explain the relationship between energy and temperature.

Using molecular level reasoning, why do ***you*** think different substances have widely varying boiling and melting points? (Do not look up an answer; use your observations and logic to reason why this phenomenon occurs. There are no wrong answers, but please give genuine answers).

What makes the individual molecules in liquid and solid phase dihydrogen monoxide 'stick' together.

Post Lab: Draw Lewis-like Structures of and name all the substances that you observed in this experiment.

A-4 Lab #4 Gas Pressure and Volume Relationships

Name__________________________ Lab Section_______________

CHECKOUT from the Storeroom: Plastic Tub containing Go!Link and Gas Pressure sensor

In this laboratory experience, you will be able to observe a classic chemistry concept from both the macroscopic and molecular point of view. It is important to be able to link the two different views when forming an understanding of chemistry.

Open the plastic tub and remove the Go!Link and gas pressure sensor and 20 mL syringe (Figure I).

Figure I.

Connect the gas pressure sensor to the Go!Link and then connect the Go!Link and gas pressure sensor assembly to the laptop through the USB port on the portable computer. Do not connect the syringe to the gas pressure sensor right away.

Log onto portable computer and open the Internet Explorer browser, and access the following web page:
http://introchem.chem.okstate.edu/jmol/GoIO1/

When the dialogbox appears click on the Trust button. This will load a particulate simulation that looks like Figure 1I.

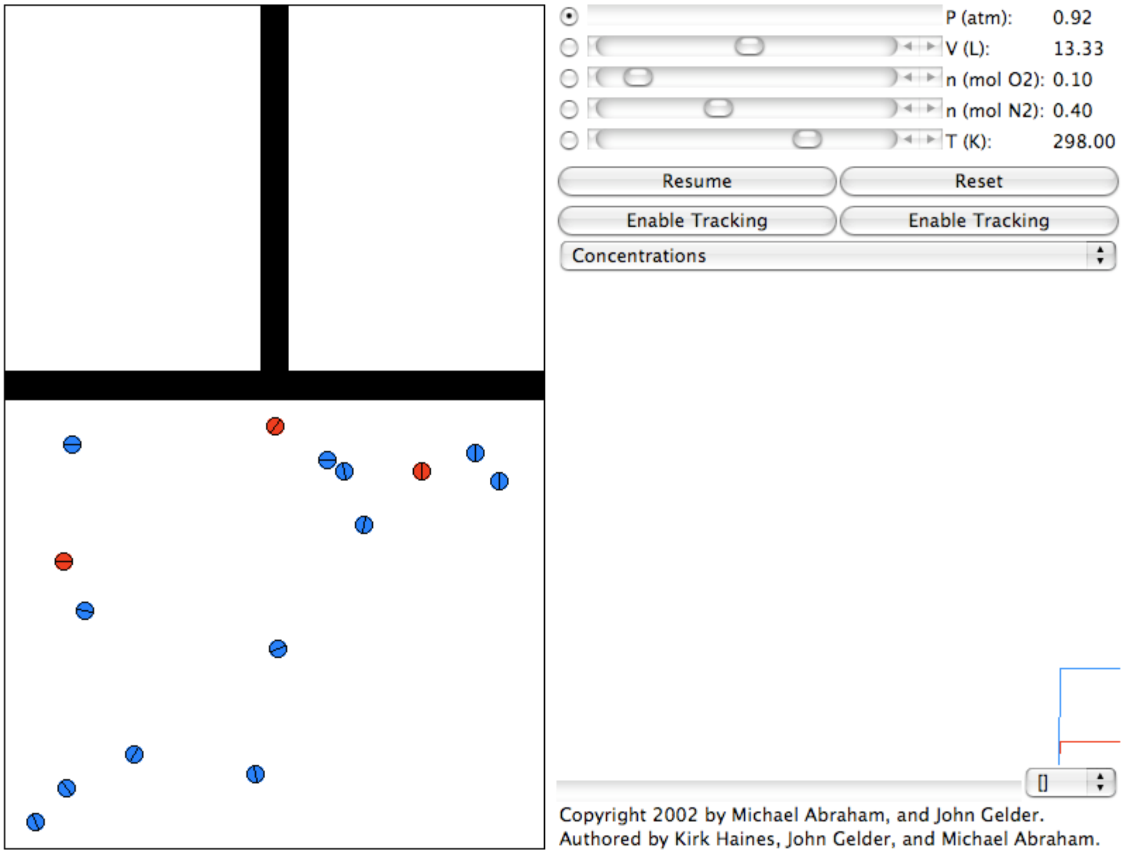


Figure II.

Once the simulation is running you may need to uncheck the Status Bar under the View option in the Menubar to see all of the simulation and control bar region.

Check the value of the volume in the upper right corner of the window on the computer screen. The volume should be read in units of mL (not L). For example in Figure II the volume of the syringe is 13.33 mLs NOT 13.33 L. Set the volume of your syringe to the volume shown in the display and attach the syringe to the gas pressure sensor. Click on the Volume radio button on the left of the volume horizontal scrollbar. If the particles are not already moving in the container shown on the left side of the display, click the Resume button.

Before getting started, familiarize yourself with the equipment and how it works.
Depress the syringe plunger and observe what happens in the simulation.
Pull the syringe plunger out and observe what happens in the simulation.
(NOTE: At this time do not change the number of moles of either gas in the container, or the temperature of the gas.)

Problem Statement: How are the pressure and volume of a gas sample related?

When you have the simulation running in the browser window (the gas particles are moving in the gas sample region), and the simulation is responding to the gas pressure sensor you are ready to begin Data Collection.

I. Data Collection

A. What are the names, formulas and relative proportion of the major gaseous components of air?

B. Based on your responses in Part I.A., identify the gas particles in gas sample region of the simulation.

C. Are the particles in the gas sample region of the simulation monoatomic or diatomic? How can you tell?

D. Observe the gas sample in the gas sample region on the computer screen. Describe what is happening on the molecular level. Consider using some or all of the following words in your description: particles, atoms, molecules, collisions, speed, energy, force.

E. Enable one of the tracking buttons to track the path of a gas particle. In the space below trace the path of the particle from one side of the container to the other. Explain any changes in speed or direction of the particle that you observe.

	Explanation:

F. Record the values for pressure, volume (remember the unit is mL), and temperature that appear on the computer screen. What is the pressure of the trapped air in your syringe?

G. Check to be sure the volume of air in your syringe compares closely to the volume of air displayed in the simulation. Does gas volume describe the space that individual molecules occupy or does volume describe the space that the individual molecules occupy and the space between molecules?

H. Depress the plunger of the syringe and describe the changes that occur in the system. Is the pressure of the trapped air greater or less than atmospheric pressure? Explain.

I. Take pressure and volume data for a total of seven data sets such that you capture data over the full range of the syringe. NOTE: The minimum volume the simulation can measure is around 5 mLs, so be careful collecting data at the low end of the volume reading. Record the pressure and volume data in the provided table.

Pressure(atm)	Volume (mL)	Pressure(atm)	Volume (mL)
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______

I. Click on the dropdown button below the two tracking buttons and select the Velocities option. Look at the velocity bar graph. Click on the Pause button and sketch and label the graph below.

J. Click on the Resume button and observe the changes in the velocity bar graph to what you see with the behavior of the particles in the gas sample window. What can you say about the speeds of the gas particles? Are they all the same? Are they different? Does the velocity of a particle remain constant?

II. Data Analysis

A. What patterns do you find from the data collected in I.H.? How are pressure and volume related? Try to come up with an algebraic relationship to express the pattern you found. (Hint: the variables are pressure and volume; try graphing the pressure and volume data in Excel. Print out the graph and include it here.)

III. Data Interpretation

A. How are the pressure and volume of a gas related?

B. Mental Model—Draw a picture(s) that explains how the pressure and volume of a gas sample are related at the level of atoms and molecules and that illustrates the observations you made in the experiment. In words, explain how your picture(s) illustrates this relationship.

C. Based on your data (I.H. and II.A), predict the pressure of a gas sample at a volume of 100 mL. Show how you made your prediction.

POST LAB QUESTIONS

1. What is the difference between the density of a gas and the mass of a gas?

2. What is the difference between the volume of a sample of gas and the volume of the same sample in the condensed liquid phase?

3. What is the difference between the mass of a sample of gas and the mass of the same gas sample in the condensed liquid phase?

4. Generate a hypothesis regarding the relationship between temperature and either volume or pressure. Briefly design and carry out an experiment in which you determine a) the relationship between pressure and temperature or b) the relationship between volume and temperature.

NOTE: To test your hypothesis, open the following page in a new browser window. You will not need the syringe and gas pressure sensor for this activity.
http://cheminfo.chem.ou.edu/~mra/CCLI2004/GLHeNeAr.htm

Hypothesis:

Independent Variable:

Dependent Variable:

Describe the experiment you performed to collect the data below:
Data Collection:

Independent Variable	Dependent Variable

Was your hypothesis supported or refuted? Explain.

A-5 Lab #5 Gaseous Diffusion

Diffusion is the spontaneous movement of particles (atoms or molecules) from an area of high concentration to an area of lower concentration until the particles are uniformly distributed. When the particles are evenly distributed, the system has reached equilibrium.

A rate is a ratio that describes the relationship between two different measurements with two different units. For instance, speed is a rate since it can be measured in miles/hour. A heart rate can be measured in beats/minute. When describing rates, it is common to express the division operator as the word 'per' (miles per hour, miles per gallon, heart beats/minute).

Think of two more examples of rates that you have encountered in your life. Include this in your pre-conceived notions.

The purpose of this experiment is to determine the relationship between the rate of diffusion and the physical characteristics of a substance (mass, size, shape etc). Develop a hypothesis that predicts how the physical characteristics will affect the rate of diffusion.

Supplies:

Ammonia, Hydrochloric Acid or hydrogen chloride, Glass tube, Ring stand, Meter stick, Cotton Balls, Stop watch, Parafilm squares, and Sodium Bicarbonate (for acid neutralization).

Procedure:

1. Fit cotton plugs 1 cm into each side of the glass tube. Use about ¼ of a cotton ball.
2. Add 10 drops of HCl to the cotton ball on one end, and 10 drops of NH3 to the cotton on the other side. Immediately cover both ends with parafilm and start the stop watch.
3. Attach the glass tube horizontally to the ring stand.
4. Observe. Do not take your eyes of the glass tube. Make observations that will allow you to determine when the HCl gas has reached the NH_3 gas. When you determine that the gasses have met somewhere in the tube, stop the time.
5. Record the time in seconds that is took for the gasses to diffuse, and measure the distance between the inner sides of each cotton ball to the area in the tube where you determined that the gases met.
6. Analyze the results and compare the results with your hypothesis.

Post-Lab

Draw a molecular level picture of the gases diffusing in the experiment that you performed today. Use arrows to portray the speed of the molecules (the larger the arrow, the greater the speed). Also make sure your model portrays NH_3 and HCl correctly. They are molecules and different atoms have different sizes

A-6 Lab #6 Liquids: Density Buoyancy, Miscibility, and Capillary Action

Part I

In your group, discuss all the factors that may affect whether or not an object will sink or float. Record your thoughts as pre-conceived notions.

Next, do some preliminary experiments using your instinct. Guess whether objects will sink or float in water.. Record your predictions for all of the solid objects before testing them for floating or sinking in water. Record the results.

Based on your above observations and results generate a hypothesis that will allow you to predict whether or not a solid will sink or float in any given liquid (not only water).

Test your hypothesis in at least three different liquids.

Next, develop a hypothesis for the volume and mass of a liquid displaced by a sunken object. Develop an experiment to test this hypothesis.

Also generate a hypothesis for the volume and mass of a liquid displaced by a floating object and experiment.

Post Lab Questions:

1. When an object floats, what forces are acting on the object keeping it from the bottom of the liquid container?
2. How does this force vary when mass stays constant, but the volume changes?

3. Does an object weigh less underwater? Develop a hypothesis and test it.

4. What is buoyancy and how does it relate to your previous experiments.

Part II

Question: What is miscibility? How can one predict if liquids will be miscible or immiscible based on their molecular structure? (What common features do molecules that are miscible with each other have? What is the trend among substances that do not form homogeneous solutions?)

Test the miscibility of mixtures of all compounds. Create a data table. Analyze the data table for patterns and trends. Record the questions, data table, and conclusion that answers both questions in your lab notebook.

Available Materials

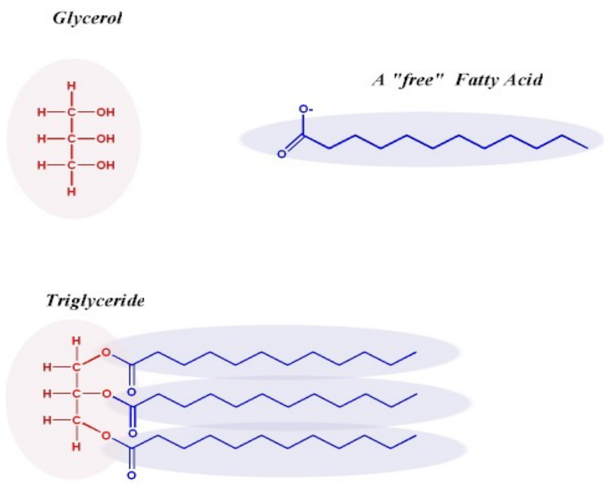
Glass capillary tubes	Water
Mineral oil	Methanol
Isopropyl Alcohol	Ethanol
Propanol	Vegetable oil (canola)
Acetone	Olive Oil
Butanol	Hexane
Pentane	Test Tubes/ Test Tube Rack

****Any mixture containing hexane or pentane must be disposed of in the organic waste container****
****Please use the minimum amount of chemical needed to make your observations****

Relevant Information:

Most oils are complex mixtures of triacylglycerides. A triacylglyceride is a three carbon glycerol chain connected to three fatty acids. Triacylglycerides (or simply called triglycerides or more simply 'fats') are a major energy reserve for both animals and plants.

Remember to use quantitative measurements (not only qualitative measurements) when collecting data. Analyze your data for patterns and trends. Remember to specifically address the main question in your conclusion.

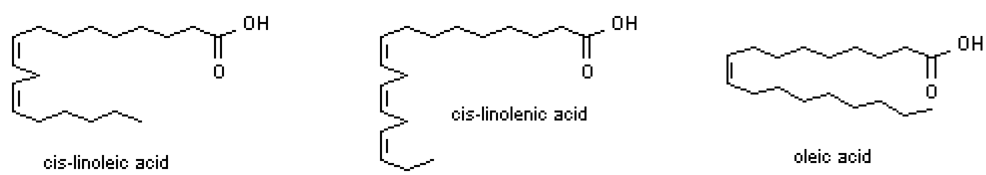


Fatty Acids:

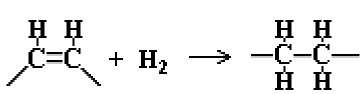
Olive Oil is a complex compound made of fatty acids, vitamins, volatile components, water soluble components and microscopic bits of olive. Primary fatty acids are **Oleic** and **linoleic** acid with a small amount of **linolenic** acid.

- **Oleic acid** is monounsaturated and makes up 55-85% of olive oil (C17H35COOH) or CH3-(CH2)7-CH=CH-(CH2)7-COOH also known as oleate.

  The IUPAC name would be *cis*-9-octadecenoate
- **Linoleic** is polyunsaturated and makes up about 9% (C17H29COOH) or CH3-(CH2)4-CH=CH-CH2-CH=CH-(CH2)7-COOH
- **Linolenic**, which is polyunsaturated, makes up 0-1.5%



Hydrogenation: Hydrogenated fat is created by bubbling hydrogen through 250 to 400 degree hot vegetable oil in the presence of a metal catalyst, usually nickel or platinum. The process can take several hours. Oleic acid (C18:1) and linoleic acid (C18:2) are both converted to stearic acid (C18:0) when fully saturated but fully saturated fats are too waxy and solid for use, hence the process is stopped at partial hydrogenation. You cannot accidentally make trans or saturated fatty acids at home on your range when heating olive oil or other oils.



Hydrogenation process

Trans Fatty acids: Olive oil has no trans fatty acids. When an oil is partially hydrogenated it can be in the cis or trans conformation which refers to which side of the fatty acid double bond the hydrogen is on. Olive oil is **not** a trans fatty acid because it has **not** been partially hydrogenated in a factory to make it solid at room temperature like margarine has.

Part III

Question: What is capillary action and by what mechanism does it work?

Experiment with different liquids and make observations about the phenomenon of capillary action. Find a quantitative way to measure capillary action.

In your lab notebook, record the question. Make a table of your observations and results. Analyze the data table for patterns and trends. Answer both parts of the question in a concluding paragraph.

Read in your text book about cohesive forces and adhesive forces.

Post-Lab Questions

1. Do you think there is a relationship between the density of a liquid and the intermolecular forces within a liquid's molecules? Explain why or why not.

2. What is (liquid) surface tension? How is surface tension related to capillary action? How is surface tension related to "The Jesus Lizard?"

A-7 Lab #7 Solids: Solubility

The **solubility** of a substance is a measure of the amount of that substance (solute) that will dissolve in a certain amount of liquid (solvent). Usually the solvent is water and solubility is expressed in grams per liter.

Pre-lab Activity:
Determine the solubility of NaCl in water at room temperature. Compare your results with other groups.

Question: Are there any periodic trends in the solubility of ionic substances, for instance are trends related in any way to ion radius or charge? Why do some solids dissolve in water while others do not?

Experiment by dissolving a few solids in water. Develop a hypothesis that states how an ion's charge or an ion's radius relates to the solubility of an ionic substance. Since ionic substances are made of two ions, each ion must be considered. Think about the intermolecular forces that would be occurring in a homogeneous solution formed from a solute (ionic substance) and a solvent (water).

Conduct a systematic experiment to test your hypothesis. Develop controls for your experiment so that any results you obtain may be contributed to your independent variable, not some other random variable.

Make sure to answer the main question on the atomic/molecular level in your conclusion.

Post-Lab: Look up how energy relates to the dissolving process. Describe the three steps in the formation of a solution and whether the energy associated with these steps is negative (releases energy) or positive (requires energy). In other words, which steps require energy to occur, and which steps release energy when they occur?

A-8 Lab #8 Mass and Particle Relationships

Name________________________________ Lab Section___________________________

Log on to the Internet. Type the following address into the location-input line of your browser:
http://cheminfo.chem.ou.edu/~mra/CCLI2004/SRGM1.htm
This will load a Particulate Simulation. Once you have the simulation running your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

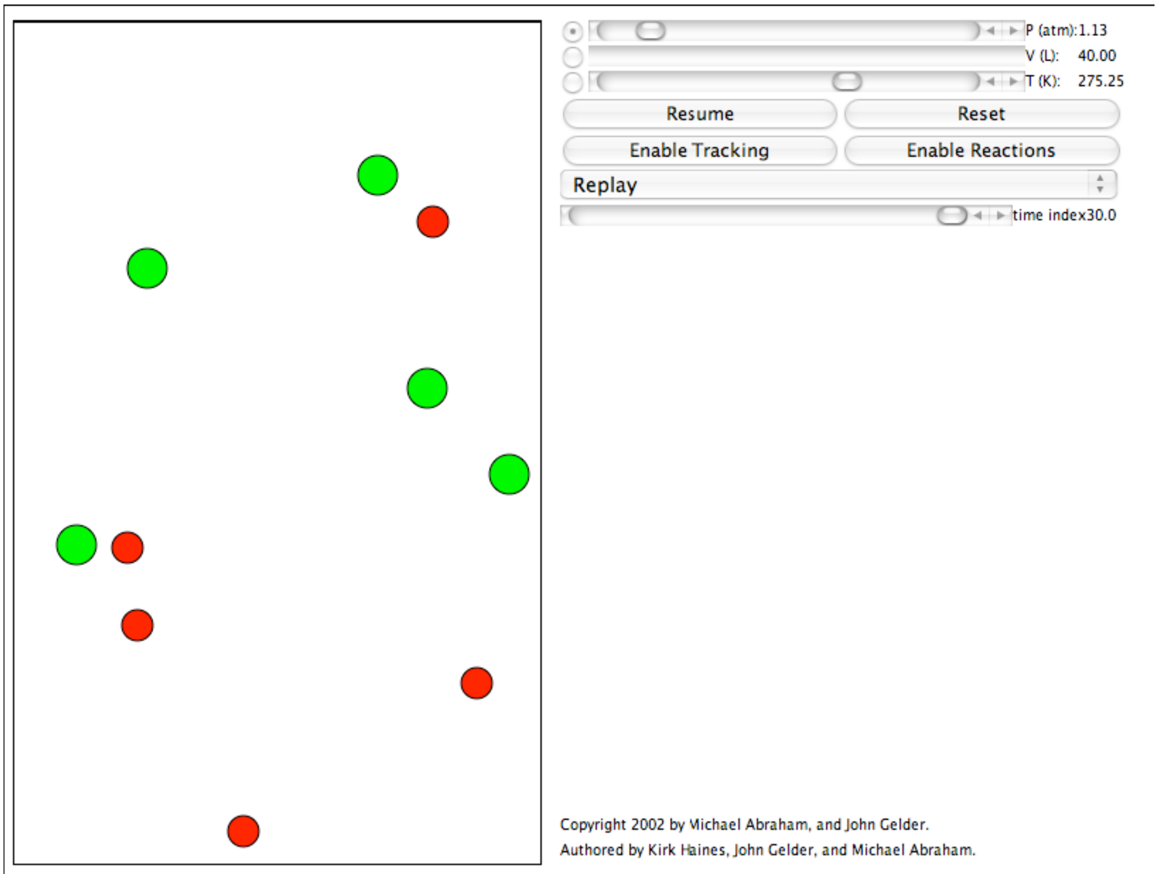


Figure 1.

Problem Statement: How are the numbers of atoms and molecules, and their masses related in a chemical reaction?

I. Data Collection:

A. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening. Use some or all of the following terms in your description: atom, molecule, particle, collision, speed, energy, reactants, and products. What is (are) the reactant(s) in this reaction? What is (are) the product(s) in this reaction?

B. Reset the simulation. Based on what you observe in the sample region and control bar region of the screen, record the number of particles of R, G, and RG in the table below. A mole is defined as a large (6.02 x 1023) number of particles. Record the number of moles of R, G, and RG in the table below.

C.

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

D. If you observe the particles in the sample region you will notice that the G particles are larger than the R particles. This is because a G particle has twice the mass of an R particle. If one mole of R particles has a mass of 1.00 gram (called the molar mass – in unit of g/mol), what is the molar mass of G and of RG? What is the mass of R, G, and RG present in the control bar region of the simulation? Record these values in the table above.

E. Click on the Enable Reaction button. Allow the simulation to run until no more changes occur. Click on the Pause button and record your observations in the table below.

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

II. Data Analysis and Interpretation:

A. In the boxes below, draw a picture representing the before (reactant) and after (product) stateof the chemical reaction you are studying. Be sure to clearly label each particle.

Before (Reactants) After (Products)

B. Write a balanced chemical equation for the reaction you have observed in this simulation. Dothis by writing an algebraic-like equation with the reactant particles on the left and theproduct particles on the right, separated by an arrow (instead of an equals sign) pointing toward the product side of the equation. Simplify the equation so that no common particles are on both side of the equation and it represents the lowest ratio of whole numbers of particles.

C. How did you decide that the reaction had reached completion?

D. The chemical equation is balanced by specifying the number of particles or moles of particles that are found as reactants and products. Do these balancing number (coefficients) also represent numbers of grams? Why or why not?

III. Data Collection:

A. Type the following address into the location-input line of your browser:
http://cheminfo.chem.ou.edu/~mra/CCLI2004/SRGM2.htm
Before starting the simulation, fill in the table below with the information requested.

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

B. Click on the Resume and Enable Reactions buttons. Allow the simulation to run until nomore changes occur. Click on the Pause button and record your observations. Fill in the table below with the information requested.

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

C. Write a balanced chemical equation for the reaction you have observed in this simulation.

IV. Data Analysis and Interpretation:

A. Compare your observations from this experiment with the one you did in section I. How were the reactions similar and how were they different?

B. Compare the equation you wrote for III.C. with the one you wrote for section II.B.

C. Predict what would happen if you started the reaction with 5 R particles and 7 G particles.

D. Compare the total amounts of atoms, molecules, and masses for the reactants with the total amounts of atoms, molecules, and masses for the products. Which of these factors are conserved as the reaction proceeds from reactants to products?

E. What is the ratio of reacting particles in this reaction? What is the ratio of reacting masses in this reaction? How are these ratios related to each other?

F. If 15 moles of R are combined with 15 moles of G, how many moles of RG will be formed? G. If 15g of R are combined with 15g of G, how many grams of RG will be formed?

V. Data Collection:
Open the molecular simulation SG2B2M:
http://cheminfo.chem.ou.edu/~mra/CCLI2004/SG2B2M.htm

A. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening. Use some or all of the following terms in your description: atom, molecule, particle, collision, speed, energy, reactants, and products. What is (are) the reactant(s) in this reaction? What is (are) the product(s) in this reaction?

B. Using the procedure you used to study the chemical reaction in the previous sections, fill in the table below with the information requested for this new chemical reaction. B particles have a molar mass of 1.500 grams per mole.

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

	R	G	RG
# of Particles			
# of moles			
Mass/mole			
Mass			

C. Write a balanced chemical equation for the reaction you have observed in this simulation.

VI. Interpretation and Conclusions:

A. Write a rule for determining the molar mass of a molecule.
B. What quantities are conserved in a chemical reaction?

C. A limiting reagent is defined as a reactant in a chemical reaction that limits or controls the amount of product that is formed. What was the limiting reagent in each of the reactions you studied in this activity?

Reaction (Section #)	Limiting Reagent
II.B.	
IV.B.	
V.C.	

D. If 20 moles of G2 are reacted with 10 moles of B2, how many moles of G2B will be formed?

E. If 20g of G2 are reacted with 10g of B2, how many grams of G2B will be formed?

VII. Data Collection:

Type the following address into the location-input line of your browser:
http://cheminfo.chem.ou.edu/~mra/CCLI2004/SRGN.htm
This will load a Graphic Simulation. Once you have the simulation running your screen will look like what is shown in Figure 2 below. If you haven't already done so, read the Graphic Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

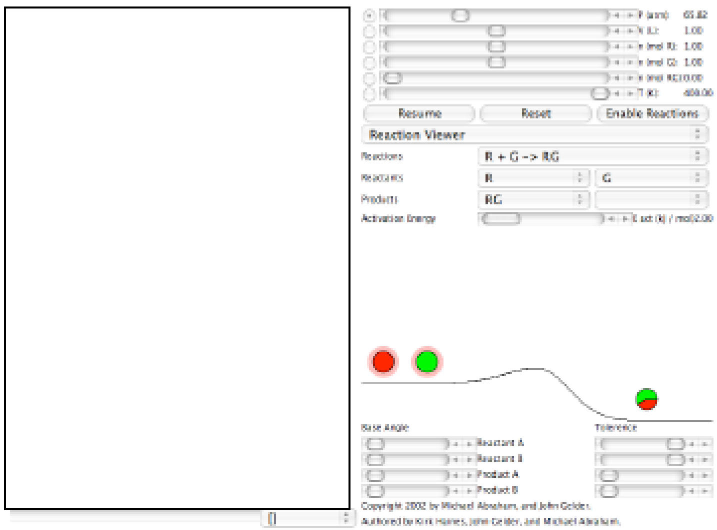


Figure 2.

A. Using the data from the Control Bar Region, enter the initial amounts (moles) of each substance in the equation into the table (called an ICE table) below.

R + G → RG
Initial Amount (moles) – I ___ ___ ___
Change (moles) – C ___ ___ ___
Ending Amount (moles) – E ___ ___ ___

B. Click on the Resume and then the Enable Reactions buttons to begin the reaction. When the reaction appears to be complete, click Pause to stop the action. Record the values of the ending concentrations in the table in Section A. Calculate and record the change in numbers of moles of each of the substances in the reaction. In the space below, draw the appearance of the strip chart and label the axes. If necessary, use the scrollbar located under the strip chart to move the chart back to the beginning of the reaction. Identify the chemical substance that corresponds to each of the colored lines.

C. The molar masses for the atoms in this activity are: R = 1.00g, G = 2.00g, and B = 1.50g. Usethis information to convert the molar data from the previous sections to fill in the ICE tablebelow with masses of the reactants and products in grams.

R + G → RG
Initial Amount (grams) – I ___ ___ ___
Change (grams) – C ___ ___ ___
Ending Amount (grams) – E ___ ___ ___

VIII. Interpretation and Conclusions:

A. Explain what is happening to each of the reactant and product substances over time. How does the strip chart illustrate the changes you observe?

B. How can you tell when the reaction is complete? What substances are present when there action appears to be complete?

C. Identify the limiting reagent for the reaction. What reagent is in excess and how much excess is there?

D. Consider the reaction you studied in section V. between G2 and B2. If 5.0g of G2 are combined with 5.0g of B2, how many grams of G2B is formed? Set up an ICE table like the ones used in previous sections. Identify any limiting reagents present and the number of grams of any reactants that are left in excess. Open the molecular simulation SG2B2N: http://cheminfo.chem.ou.edu/~mra/CCLI2004/SG2B2N.htm to confirm your conclusions.

A-9 Lab #9 Observing Chemical Reactions

1. What is a chemical reaction?

2. Name three observations that may indicate a chemical reaction has occurred.

Choose a chemical reaction that you observed in class to analyze.

3. Write the balanced chemical equation.

4. List properties of each reactant before the reaction and properties of each product after the reaction has occurred.

5. Describe the reaction when you use a lot of one reactant and a minute amount of the other reactant.

6. Describe the reaction in reverse conditions.

7. Chemical kinetics is the study of the rate of a reaction.

8. How could you tell if a reaction is done reacting?

9. Approximately how long did it take for the reaction to go to completion?

10. Does stirring increase the rate of reaction?

11. If 1 gram of each of your reactants react, how much of each product will be formed (in grams)?

12. If .23 moles of each reactant combined, how much of each product will be formed (in moles)?

Write a balanced chemical equation for the reaction of...

13. Nitrogen gas with hydrogen gas to form ammonia gas:

14. Sodium metal with hydrochloric acid to form sodium chloride and hydrogen gas

15. Pentane liquid and oxygen gas to form carbon dioxide and water

16. Calcium metal and oxygen gas to form calcium oxide

17. Hydrogen gas and oxygen gas to form water

18. Solid sodium hydroxide and carbon dioxide to form sodium bicarbonate

19. Ammonia gas and hydrochloric acid gas to form ammonium chloride

20. Calcium Carbonate (s) forming calcium oxide and carbon dioxide

21. How many moles of water are formed when 2 moles of oxygen react with 2 moles of hydrogen?

22. How many moles of water are formed when 2 moles of oxygen react with 1 mole of hydrogen?

A-10 Lab #10 Acids and Bases

Acid- A substance that donates hydrogen ions.

Base- A substance that accepts hydrogen ions.

$pH = -log[H^+]$

Acids can be represented by the generic formula HA where H is the hydrogen ion and A is any anion (negatively charged ion).

Bases can be represented by the generic formula MOH where M is any metal cation, and OH^- is the polyatomic anion hydroxide.

When acids and bases react, it is called a neutralization reaction.

Common Acids:

hydrochloric acid (HCl, secreted by the stomach to help digest food, swimming pool additive to kill algae,aka muriatic acid)

acetic acid ($HC_6H_{12}O_6$, found in low concentrations (5%) in vinegar)

sulfuric acid (H_2SO_4, found in car batteries)

phosphoric acid (H_3PO_4, it is in your Dr. Pepper, and is also used to remove rust from iron, and adjust the pH of cosmetics)

citric acid ($C_6H_8O_7$, found in citrus fruits)

boric acid (H_3BO_3, used in antiseptic solutions, eyewash, insecticide, and flame retardant)

Common Bases: Sodium hydroxide (NaOH also known as lye)

Ammonia (NH_3, this formula does not follow the general base formula pattern, but it is still a base)

Potassium hydroxide (KOH)

Lithium Hydroxide (LiOH)

Calcium Hydroxide ($Ca(OH)_2$)

Rubidium Hydroxide (RbOH)

Barium Hydroxide ($Ba(OH)_2$)

Question: What are the properties of acids and bases?

Do preliminary experimentation with the different chemicals provided and make observations and generalizations about acids, bases, and acids mixed with bases using litmus paper, pH meters

Make a table to display your observations.

Do not touch, taste, or smell any chemical.

In your result/conclusion section, make at least 3 generalizations about acids and 3 generalizations about bases that came from your observations in this lab.

Perform research to find 3 instances where acids, bases, or pH affect life. Describe these instances and the relation to your life in the post-lab section.

A-11 Lab#11 Releasing Chemical Potential Energy of Food

Bond Energy- The amount of energy either required to break a chemical bond or the amount of energy released as a bond forms.

Bond Energies

C-H Bond = 99 kcal/mole

H-O Bond = 111 kcal/mole

C-C Bond = 83 kcal/mole

C-O Bond = 85.5 kcal/mole

All chemical bonds contain chemical potential energy. Chemical potential energy is stored energy that can be released later. Burning a compound is one way to break bonds and release chemical potential energy.

Carbohydrates are molecules composed of only carbon, hydrogen, and oxygen atoms, thus it can be classified as a biomolecule. Carbohydrates are produced by plants via photosynthesis. Carbohydrates are soluble in water since their molecules have a lot of -OH groups which provide for significant hydrogen bonding between molecules of water and molecules of carbohydrates. Some examples of carbohydrates are glucose, sucrose, and lactose.

Proteins are also biomolecules, but they are polymerized to form very long chains. Proteins are very long chains of lots of amino acids linked together through bonds. When proteins are digested, they are broken down into amino acids so they can be transported into the cell where they will be polymerized into new proteins.

Fats are biomolecules that store a lot of energy per gram. They consist of a glycerol unit bound to three fatty acid molecules. Fats are not soluble in water due to the poor interactions between polar water and the long non-polar hydrocarbon chains of the fatty acids. Examples of fats are canola oil, olive oil, and animal fat.

Metabolism is a general term that describes all the chemical reactions of the body.

Calorimetry is the science of measuring the heat associated with a chemical reaction (or a physical process). A calorimeter is a device that is used to measure the amount of heat transferred in a process which is accomplished by noting the temperature change of water inside the calorimeter.

Heat released by reaction = (water mass)(specific heat of water)(T_f-T_i) + (calorimeter mass)(specific heat of calorimeter)(T_f-T_i)

The specific heat of water is 1 cal/(g-C).

The specific heat of tin can be empirically determined.

Form a hypothesis as to the relative amounts of energy that will be released when foods predominately made from carbohydrates are burned versus foods that are high in fat.

Develop a procedure to test your hypothesis based on the calorimetry strategy that we discussed in class. You may expand on the general idea by designing a calorimeter that is more insulated from the atmosphere (and thus looses less heat to the atmosphere) or that makes the experiment more reliable using any available materials.

Design (a) table(s) to display your experimental data.

Show examples of all calculations you performed using real data.

Briefly state your results, and then write a conclusion paragraph that includes how you were able to calculate the amount of energy in food and what you learned during this experiment. Compare a molecule of a fat to a molecule of a carbohydrate and suggest why fats may have more calories per gram than carbohydrates.

A-12 Lab#12 Synopsis of Chemistry Related Journal Article

Research of current literature is part of every good chemist's repertoire (the entire stock of skills, techniques, or devices used in a particular field or occupation).
As such, it should also be part of your repertoire.

For the last lab, your duty is to research a current issue in chemistry and give a short 5-10 minute presentation for the class.
In class today, you may go to www.library.okstate.edu and find an article

-The Journal of Chemical Education

-Science

-Chemical Week

-Chemistry

-Science and Culture

-Science and Society

-Science and Technology

-Science and Public Affairs

-Science of Food, Agriculture, and Environment

-Science Technology and Human Values

Your report should be written (1 page minimum, double spaced) as well as orally delivered to the class.
Also, please turn in a copy of the article(s) you used.
Your grade for his assignment will be graded based on 4 criteria:

Relevance to the Field of Chemistry- 5 points

Incorporation of some (at least one) concept that we have previously discussed in this course or the incorporation of chemical education/science literacy- 5 points

Grammar, spelling, etc. - 5 points

Overall effort and attitude - 5 points

APPENDIX B

ASSESSMENT INSTRUMENTS

B-1 Previous Coursework Questionnaire

Name and Email Address:

Please list the science courses you completed in high school:

Please list the math classes you completed in high school:

Please list any science classes you have completed in college:

Please list any math classes you have completed in college:

What are your future career goals?

What do you hope to learn from this class?

B-2 Field-Independence Questionnaire

1 = I Agree

2 = I am Ambivalent

3 = I Disagree

It is important for teachers to let students develop their own ways of solving problems.

I prefer learning in class with other students rather than learning by myself at home.

A good teacher always gives clear directions.

Creativity is an innate characteristic of some people.

I like to regulate my own learning.

Intelligence can be learned.

Teachers should limit topics covered in class to the topics covered in the textbook.

I do my best in highly structured situations.

Intelligence is an innate characteristic.

I am confident in my ability to analyze data in order to find answers to my questions.

I would rather someone I trust think for me, and give me directions when I find myself in complex situations.

Students can best learn information when the teacher has presented the information to the whole class in a lecture.

Creativity can be learned.

I am confident in my ability to analyze data and make my own conclusions.

I like to think my way out of complex situations.

B-3 Exams

B-3a Exam #1

1. What is the charge on an atom of fluorine that has gained 1 electron? (1 pt)

2. What is the charge on an atom of sodium that has lost 1 electron? (1 pt)

3. Draw a shell model for an atom of each calcium, potassium, and sodium that reflects the structure of atoms as presented in class. Make sure that your models represent atomic structure theory in terms of size and mass and organization. (5 pts)

4. It is found that as variable A decreases, variable B also decreases. Draw a general graph that represents this relationship, and label the axes. (1 pt)

5. It is found that as the volume of a sample of compound is increased the density of this sample does not increase or decrease. Represent this phenomenon graphically and be sure to label your graphs. (2.5 pts)

6. It is also found that as the mass of a sample of a compound is increased the density of the sample does not increase or decrease. Represent this phenomenon graphically and be sure to label your graphs. (2.5 pts)

7. Explain why a sulfur atom is larger than a fluorine atom. Be sure to include the words group, period, shell, electron(s), proton(s), effective nuclear charge, and shielding in your answer. (5 pts)

8. Explain why an oxygen atom is larger than a fluorine atom. Be sure to include the words group, period, shell, electron(s), proton(s), effective nuclear charge, and shielding in your answer. (5 pts)

9. Which atom would you expect to be more electronegative based on the trends discussed in class: Phosphorous or Nitrogen. Circle one. (1 pt)

10. Which atom would you expect to be more electronegative based on the trends discussed in class: Carbon or Boron. Explain why on the atomic level (electrons, protons etc). (5 pts)

11. How many shells does an atom of Mg have? (1 pt)

12. How many valence electrons does an atom of Si have? (1 pt)

13. Balance the following chemical reactions: (5 pts)

    $\_\_Na + \_\_Cl_2 \rightarrow \_\_NaCl$

    $\_\_C_2H_6 + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O$

    $\_\_BF_3 \rightarrow \_\_B + \_\_F_2$

    $\_\_S + \_\_O_2 \rightarrow \_\_SO_2$

    $\_\_H_2 + \_\_C + \_\_N_2 \rightarrow \_\_HCN$

14. What law makes it necessary to balance chemical equations? (3 pts)

15. What are the structural similarities and differences between isotopes of the same element? (2.5)

16. What are the structural similarities and differences between neutral atoms and charged atoms (ion) of the same element? (2.5 pts)

17. The balanced chemical equation for the formation of water from hydrogen and oxygen is as follows:

$$2H_2 + O_2 \rightarrow 2H_2O$$

How many water molecules can one make if only 15 hydrogen molecules and 6 oxygen molecules are available? Which reactant limits the amount of product that can be formed? (5 pts).

18. The molecular mass of a molecule is equal to the sum of the atomic masses of each atom in the molecule.

Find the molecular masses of the following molecules: (1 pt)

H_2O ________
NH_3_________
C_3H_8_______

Bonus Question: Explain *why* electronegativity decreases as one moves down a group. Do not merely state the trend. (5 pts)

B-3b Exam #2

Choose the one BEST answer:

1. True or False
   When liquid nitrogen evaporates at room temperature, N_2 molecules become N atoms.

2. Draw a lewis structure for a covalent compound composed of only two elements, one of which has five valence electrons and the other which has one valence electron. You can use A and B as the symbols for the two elements.

3. True or False

Atoms that constitute a molecule may have different electronegative values or equal electronegative values depending on their size and effective nuclear charge. When atoms within a molecule have differences in electronegative values (greater than .5) they are polar. If the atoms in a molecule have equivalent or near equivalent electronegative values (a difference of less than .5) the molecule will be non-polar.

4. Why are ethanol (CH_3OH) and water miscible?

   a. The dipole of the water molecule interacts with the temporary dipole of the ethanol molecule.
   b. They do not mix because water is polar and ethanol is non-polar.
   c. Water and ethanol molecules form strong dipole-dipole intermolecular forces that allow them to mix in any proportion
   d. Since both liquids are colorless, it is impossible to tell if they are actually miscible or not.
   e. The ion to ion force of attraction between the two molecules is great enough that the molecules overcome cohesive forces to form adhesive forces.

Short-Answer

5. What are the two main constituents of air? Provide a name and chemical formula.

6. What is the formula for Barium Bromide?

7. What charge does nitrogen take in an ionic compound?

8. How many bonds does nitrogen usually form in a covalent compound?

Fill in the blank

9. A sample of gas is at constant temperature and at constant volume. When the number of moles of gas in the container is increased, the pressure will ________________.

10. At constant temperature and composition (# of moles), if volume is decreased pressure will ____________________.

11. At constant pressure and composition, if temperature is increased, volume will ______________.

12. The stronger the intermolecular forces in a substance, the ________________ the boiling point of the substance.

Multiple-Choice

13. How many moles are in 56 grams of Au (Gold)?

a. 10,976 moles
b. 3.52 moles
c. 9.11 x 10^{-5} moles
d. .284 moles

14. How many atoms are in 56 grams of Au?

a. 4.72 x 10^{25} atoms
b. 1.71 x 10^{23} atoms
c. 6.02 x 10^{23} atoms
d. 196.96 atoms

15. How many atoms are in a mole of Au?

a. .284 atoms
b. 6.02 x 10^{23} atoms
c. 196 atoms
d. 12.04 x 10^{23} atoms

Calculations (Show Work)

16. How many grams are in 10 mL of a solution whose density is 1.4 grams/mL (grams per mL)

17. How much would 5,000,000 water molecules weigh in grams?

18. What is the pressure of a .225 mole sample of gas at 100 degrees Celsius in a 100 mL container?

Short Answer

19. What intermolecular forces keep Nitrogen molecules in the liquid phase at -196 degrees Celsius?

20. Draw a picture of three nitrogen molecules experiencing this force at -196 degrees Celsius.

21. Which is a stronger intermolecular force, ion-ion or dipole-dipole?

22. What is the reason for your answer for #21?

23. Order the following substances in order of lowest melting point to highest melting point. Chlorine is a gas at room temperature.

KCl F_2 H_2O Al_2O_3 Cl_2

24. If a substance decomposes before it boils which forces are greater for that substance: intermolecular forces or intramolecular forces?

25. What is happening to the molecules of a substance as the temperature of a substance is increasing at the macroscopic level?

Bonus

26. Suggest a lewis structure for C_7H_{16}

B-3c Exam #3

Fill in the blanks! (5 pts)

1. Substances that ionize in aqueous solutions to form hydrogen ions are ________________.
2. Substances that produce OH^- ions when dissolved in water are _____________________.
3. Acids that completely ionize in water are called ___________________________________.
4. A reaction between an acid and a base is called a __________________________________.
5. A reaction between an acid and a metal hydroxide always produces_____________________.

When HCl reacts with H_2O, what products are formed? Symbolically draw this chemical reaction using an atomic view of atoms. (Think about the internet lab, where we drew pictures of the reactants before a collision and the products after the collision). (5 pts)

Hydrofluoric acid is a weak acid. In an aqueous solution of hydrofluoric acid, is most of the acid associated or dissociated? Draw an atomic level picture that conveys your understanding of a weak acid in solution. Since the solution is aqueous, there are obviously lots of water molecules in the solution, you may draw some of the water molecules, but if you leave them out be sure to recognize that there are lots of water molecules present. (5 pts)

If Quaker Oatmeal Squares™ breakfast cereal has 4 Calories per gram of energy, how many Calories will one consume if one eats 0.45 pounds of squares? 1 lb = 454 grams. (3 pts)

The results of a calorimeter experiment show that oat squares only produce 2.3 Calories/gram.
Mass of water → 45 g
Mass of calorimeter → 74 g
Specific Heat Capacity of water → 1 calorie/gram*C
Specific Heat Capacity of calorimeter → .22 calorie/gram*C
Mass of oat square burned → .29 grams
What was the change in temperature in this calorimeter experiment? (5 pts)

Why were the results off by a few calories per gram (2.3 versus 4.0 Cal./gram)? (1 pt)

What could you do to improve the results of the experiment? (1pt)

Calculate the specific heat of a substance that has a mass of 25 grams, and when 2500 calories of heat are added, the substances temperature increases from 24 degrees Celsius to 39 degrees Celsius. Make sure to use the correct units for the specific heat capacity. (5 pts)

Consider the reaction $P_4 + O_2 \rightarrow P_2O_5$

Balance the reaction (1 pt).

Find the molecular weights of all the substances in the equation (1 pt).

If 14 grams of P_4 is allowed to react with 8.5 grams of O_2 how many grams of P_2O_5 will be formed? (5 pts)

What is the limiting reactant? (1 pt)
How much excess reactant is left over after the reaction? (2 pts)

Draw a picture of the reaction at the atomic level (before and after). (5 pts)

How would the situation change if there were originally 6 grams of P_4 reacting with 6 grams of O_2?
Indicate either yes or no to the following possible changes.
(5 pts)
The balanced chemical equation will change.

The limiting reactant will change.

The excess reactant will change.

The product will change.

The amount of the product will change.

5

Extra Credit: (5 pts)
The equilibrium constant of a weak acid, HA, is $K_{eq} = 1.6 \times 10^{-5}$.
Assume that the dissociation reaction for HA is: $HA \rightarrow H^+ + A^-$
Starting with 1.2 M HA, what is the pH of this solution?

Quadratic Equation: $\dfrac{-b \pm [b^2 - 4ac]^{1/2}}{2a}$

B-4 Alternative Assessments

B-4a Alternative Assessment #1

Go to http://pbs.org/wgbh/nova/sciencenow/3313/02.html.

1. Take the elemental quiz. Type the question, the correct answer (not only the letter) and a short explanation in your own words for all 8 questions. You may also copy the questions answers and explanations in hand writing and physically turn it in. Do your best, but you can take the quiz as many times as you like. The answers are provided.

1. **The periodic table is a chart of all known chemical elements, both natural and synthesized. Why are the elements arranged in a curious pattern of unequal rows and columns?**
    a. to reflect chemical properties
    b. to indicate when they were discovered
    c. to leave room for notes

2. **Hydrogen is the first element on the table, helium the second, lithium the third, and so on. What determines an element's numerical order?**
    a. its atomic weight
    b. the number of protons it has
    c. when it was discovered

3. **Most elements were created inside of stars, but scientists have now made more than 20 elements in laboratories. What was the first element synthesized in a lab?**
    a. technetium (element number 43) in 1937
    b. neptunium (element number 93) in 1940
    c. nobelium (element number 102) in 1958

4. **Who officially names a newly discovered element?**
    a. the researcher(s) who discovered it
    b. the institution where it was discovered
    c. an international group of chemists

5. **What everyday object makes use of a synthesized heavy element?**
    a. a smoke detector
    b. a microwave oven
    c. a fluorescent light

6. **In 1952, elements 99 and 100 were discovered. Where were they found?**
    a. in a particle accelerator in Stockholm
    b. in pitchblende, a uranium-rich ore
    c. in debris from a hydrogen bomb test

7. **The nuclei of elements with a so-called "magic number" of protons tend to be more stable. What is the heaviest element found in nature with such a magic number?**
    a. calcium
    b. lead
    c. nickel

8. **In the 1960s, physicists predicted that if element 114 could be made, it would be more stable than other super heavy elements. In 1998, when scientists finally created a single atom of element 114, it survived for how long?**
    a. 30 seconds
    b. 30 hours

c. 30 days

2. Watch the 13 minute segment *Island of Stability*. Write a summary of the video in 1 page or less.

3. What would you name element number 114, and why would you name it that?

4. Based on where the element would fall on the periodic table of elements, predict some chemical and physical characteristics that you would expect element 114 to have.

5. A block of an unknown material has a density of 4.0 g/cm^3 and a volume of 28 cm^3. The block is cut into two pieces. One piece has a volume of 18 cm^3 and the other piece has a volume of 10 cm^3. What are the densities of the two pieces? Explain.

6 Compare and contrast the elements sulfur and magnesium. Be as through as possible.

7. Explain how gaseous diffusion helped the Allies win World War II. Be sure to explain the process of diffusion and the factors that affect diffusion in your explanation.

B-4b Alternative Assessment #2

Molecular Menagerie

http://www.hhmi.org/biointeractive/genomics/molmod/index.html

Copy and paste this link into the internet browser or follow the link from the class website.
Go through the molecular menagerie tutorial and use the tutorial to answer the following questions.
Pay particularly close attention to the first slide which explains how to interpret condensed chemical structures. It may help you to draw structures out longhand. This web site is specifically for questions 1-4.

1. Glucose is the main sugar in our bloodstream. Does glucose dissolve in the blood? Why or why not? Consider the major components of blood, their molecular structures and the molecular structure of glucose when explaining your answer.

1. Would a lone molecule of cholesterol dissolve in the bloodstream? Why or why not? Consider the major components of blood, their molecular structures and the molecular structure of cholesterol when explaining your answer.

1. Does aspartame dissolve in our bloodstream? Why or why not? Consider the major components of blood, their molecular structures and the molecular structure of aspartame when explaining you answer.

2. Which would you expect to have a higher boiling point: caffeine or aspartame? Explain your reasoning on the molecular level.

2. Which would you expect to have a higher boiling point: ibuprofen or aspirin? Explain your reasoning on the molecular level.

2. Which would you expect to have a higher boiling point: testosterone or estradiol? Explain your reasoning on the molecular level.

3. Aztrizine, an ingredient in weed killers, has the chemical formula of $C_8H_{14}ClN_5$. How many hydrogen bonding sites (places) are there on the aztrizine molecules? Draw the structure and label the places where this molecule could form hydrogen bonds with other molecules.

3. Prozac, an medicine that boosts levels of the neurotransmitter seretonin, has the formula $C_{17}H_{18}F_3NO$. How many hydrogen bonding sites (places) are there on the Prozac (fluoxitine) molecule? Draw the structure of the molecule and label the places where the molecule is capable of forming hydrogen bonds with other molecules. Draw the complete structure showing all atoms and all bonds.

3. Penicillin, an antibiotic (anti-bacterial) medicine, has the formula $C_{16}H_{18}N_2O_4S$. How many hydrogen bonding sites (places) are there on the penicillin molecule? Draw the structure of the molecule and label the places where the molecule is capable of forming hydrogen bonds with other molecules. Draw the complete structure, showing all atoms and all bonds.

4. What is the molecular weight of Rapamycin?

4. What is the molecular weight of testosterone?

4. What is the molecular weight of estradiol?

5. Why is carbon dioxide a gas at room temperature?

5. Why is nitrogen a gas at room temperature?

5. Why is oxygen a gas at room temperature?

6. Notsae, notsob, and laicos are fictional units. If there are 14 notsae in one notsob, and there are 72 notsob in one laicos, convert 23 notsae to units of laicos. Show all work for full credit.
6. Tramlaw, retaw, and noinu are fictional units. If there are 20 noinu in one retaw, and there are 33 tramlaw in one retaw, convert 14 noinu to units of tramlaw. Show all work for full credit.
6. Snopu, egell, and skoorb are fictional units. If there are 12 egell in one skoorb, and there are 6 snopu in one egell, convert 51 snopu to units of skoorb. Show all work for full credit.

7. Write the chemical formula for potassium sulfide. Draw an atomic level view of potassium sulfide dissolved in water. How many moles are in 2.0 grams of potassium sulfide?

7. Write the chemical formula for calcium bromide. Draw an atomic level view of calcium bromide dissolved in water. How many moles are in 2.0 grams of calcium bromide?

7. Write the chemical formula for sodium iodide. Draw an atomic level view of sodium iodide dissolved in water. How many moles are in 2.0 grams of sodium iodide?

8. How do metals and non-metals differ when forming ions?
8. How do group 1 metals and group 2 metals differ when forming ions?
8. How do group 16 non-metals differ from group 17 non-metals when forming ions?

9. Develop an experimental procedure to determine the relationship between number of moles of gas and gas pressure. Be sure to name your dependent and independent variable.
9. Develop an experimental procedure to determine the relationship between number of moles of gas and gas temperature. Be sure to name your dependent and independent variable.
9. Develop an experimental procedure to determine the relationship between number of moles of gas and volume.

You may use the simulation found at http://introchem.chem.okstate.edu/jmol/GoIo1/ to design your experiment, or you may design a macroscopic experiment using laboratory equipment.
10. All substances exhibit london dispersion forces (ldf), and non-polar molecules only exhibit ldf.Which of the following substances would have stronger ldf between two identical molecules:pentane or heptane? You will need to look up the structures of these compounds in order to explain your reasoning on the molecular level.

10. All substances exhibit london dispersion forces (ldf), and non-polar molecules only exhibit ldf.Which of the following substances would have stronger ldf between two identical molecules: hexane or nonane? You will need to look up the structures of these compounds in order to explain your reasoning on the molecular level.

10. All substances exhibit london dispersion forces (ldf), but non-polar molecules only exhibit ldf. Which of the following substances would have stronger ldf between two identical molecules: butane or octane? You will need to look up the structures of these compounds in order to explain your reasoning on the molecular level.

There are 10 questions worth 5 points each. Every question will be graded according to the following rubric:

1 point   correct answer
2 points correct reasoning
1 point correct use of chemistry vocabulary as opposed to common vernacular
1 point sentence structure/grammar

B-4c Alternative Assessment #3

I. Why is some drinking water fluoridated?

How is drinking water fluoridated?

What are the benefits of fluoridated drinking water?

What are the risks of fluoridated drinking water?

Would you prefer you and your family's water be fluoridated? Why or why not?

(10 points for a paragraph that answers all these questions)

II. Balance the following chemical reactions (5 points):

$H_20_{(l)} + F_{2(g)}$ -> $2HF_{(aq)} + O_{3(g)}$

$H^+_{(aq)} + OH^-_{(aq)}$ -> $H_2O_{(l)}$

$H_{2(g)} + S_{8(s)} + O_{2(g)}$ --> $H_2SO_{4(aq)}$

$Na_{(s)} + H_2O_{(l)}$ --> $NaOH_{(aq)} + H_{2(g)}$

$K_{(s)} + H_2O_{(l)}$ --> $KOH_{(aq)} + H_{2(g)}$

III. How much heat must be added in order to increase the temperature of a 79 gram sample of water by 4 degrees Celsius? Show your work! (5 points)

IV. Calculate the effective nuclear charges for every atom in the second period and describe how the effective nuclear charge relates to the atomic radius of an atom (8 points). Show your work!

V. Why is a sodium atom larger than a magnesium atom (4 points)?

VI. Predict the products of the following reactions: (3 points)

$Ba_{(s)} + HCl_{(aq)}$ -->

$Ag^+_{(aq)} + Cl^-_{(aq)}$ -->

$Xe_{(g)} + F_{2(g)}$ -->

VII. Associate the following words with a type of energy (kinetic energy, potential energy, or radiant energy) OR a processing of energy (storing energy, releasing energy) or both. (Up to 5 points for 5 correct associations, but you must *try* to assign an energy classification to all 11 words)

Running

Growing plants

Light

Food

Heat

X-Rays

Microwaving Food

Sun-tanning

Solar Power

Wind Energy

Chemical Bond

VIII. Define specific heat and look up the specific heat of three different substances (5 points).

http://en.wikipedia.org/wiki/Specific_heat

Substance	Specific Heat
__________	____________
__________	____________
__________	____________

B-5 Chemical Concepts Inventory

This inventory consists of 22 multiple choice questions. Carefully consider each question and indicate the one best answer for each. Several of the questions are paired. In these cases, the first question asks about a chemical or physical effect. The second question then asks for the reason for the observed effect.

1. Which of the following must be the same before and after a chemical reaction?

   a. The sum of the masses of all substances involved.
   b. The number of molecules of all substances involved.
   c. The number of atoms of each type involved.
   d. Both (a) and (c) must be the same.
   e. (e) Each of the answers (a), (b), and (c) must be the same.

2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

   a. Air.
   b. Oxygen gas and hydrogen gas.
   c. Oxygen.
   d. Water vapor.
   e. Heat.

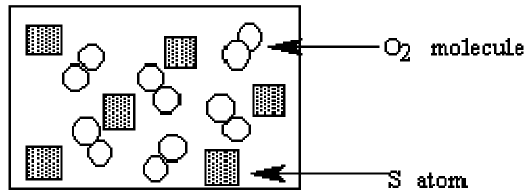
3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?

   a. Water evaporates from the milk and condenses on the outside of the glass.
   b. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
   c. Water vapor condenses from the air.
   d. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?

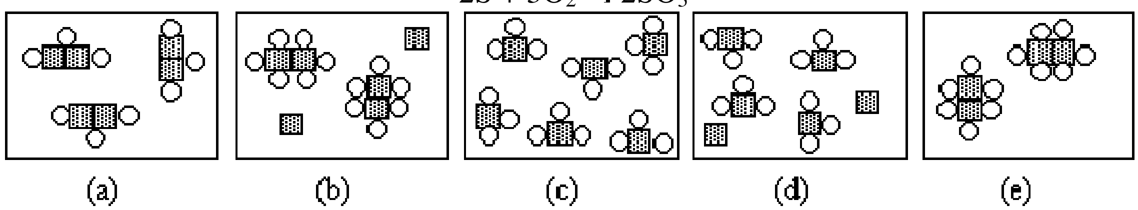
   a. 19 Pounds.
   b. 20 Pounds.
   c. Between 20 and 21 pounds.
   d. 21 pounds.
   e. More than 21 pounds.

5. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.

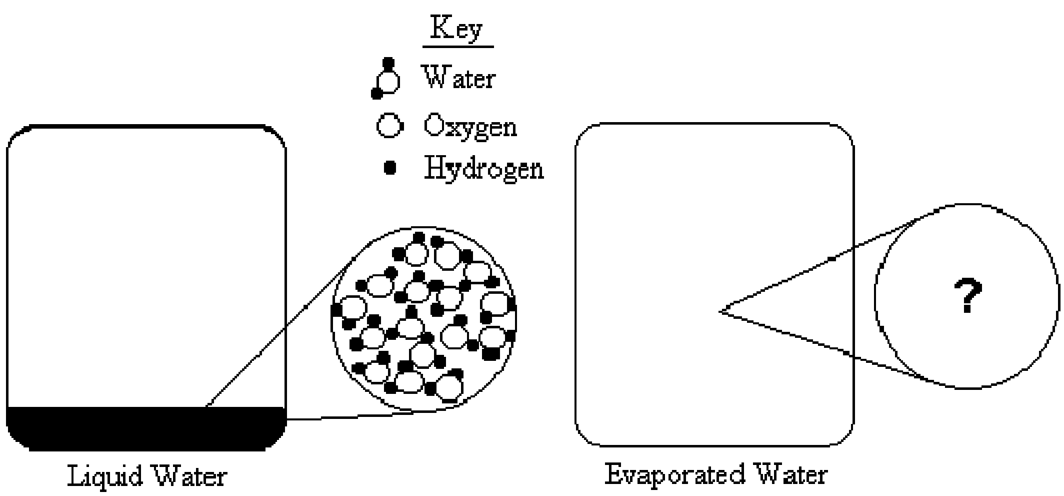


Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

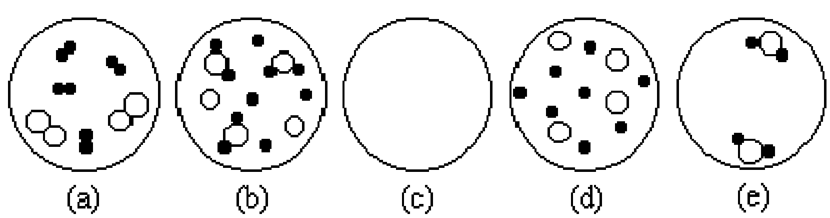
$$2S + 3O_2 \rightarrow 2SO_3$$



6. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



What would the magnified view show after the water evaporates?



7. True or False? When a match burns, some matter is destroyed.

a. True

b. False

8. What is the reason for your answer to question 7?

a. This chemical reaction destroys matter.
b. Matter is consumed by the flame.
c. The mass of ash is less than the match it came from.
d. The atoms are not destroyed, they are only rearranged.
e. The match weighs less after burning.

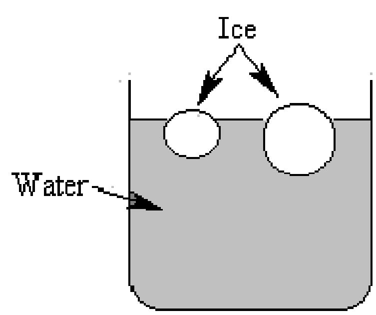
9. Heat is given off when hydrogen burns in air according to the equation

$$2H_2 + O_2 \rightarrow 2H_2O$$

Which of the following is responsible for the heat?

a. Breaking hydrogen bonds gives off energy.
b. Breaking oxygen bonds gives off energy.
c. Forming hydrogen-oxygen bonds gives off energy.
d. Both (a) and (b) are responsible.
e. (a), (b), and (c) are responsible.

10. Two ice cubes are floating in water:



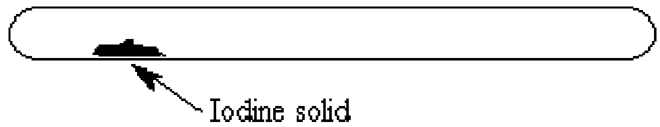
After the ice melts, will the water level be:

a. higher?
b. lower?
c. the same?

11. What is the reason for your answer to question 10?

a. The weight of water displaced is equal to the weight of the ice.
b. Water is more dense in its solid form (ice).
c. Water molecules displace more volume than ice molecules.
d. The water from the ice melting changes the water level.
e. When ice melts, its molecules expand.

12. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

a. less than 26.0 grams.
b. 26.0 grams.
c. 27.0 grams.
d. 28.0 grams.
e. more than 28.0 grams.

13. What is the reason for your answer to question 12?

a. A gas weighs less than a solid.
b. Mass is conserved.
c. Iodine gas is less dense than solid iodine.
d. Gasses rise.
e. Iodine gas is lighter than air.

14. What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: ▪

a. 4
b. 200
c. 30,000,000
d. 6.02×10^{23}

15. Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown.

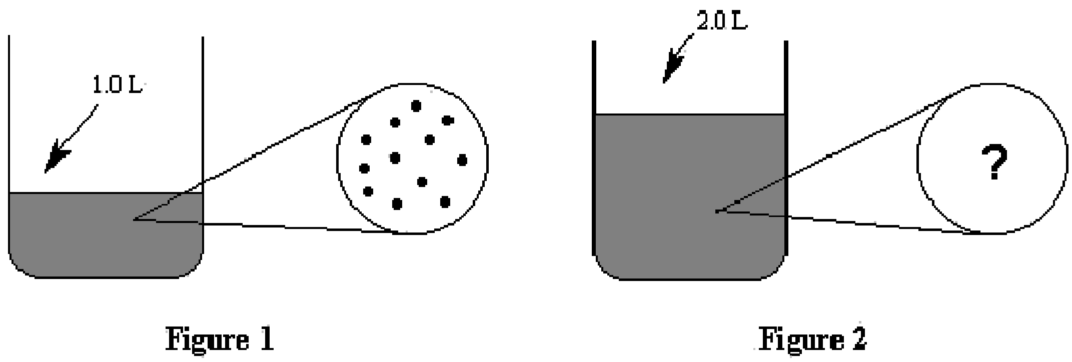


Figure 1

Which response represents the view after 1.0 L of water was added (Figure 2).

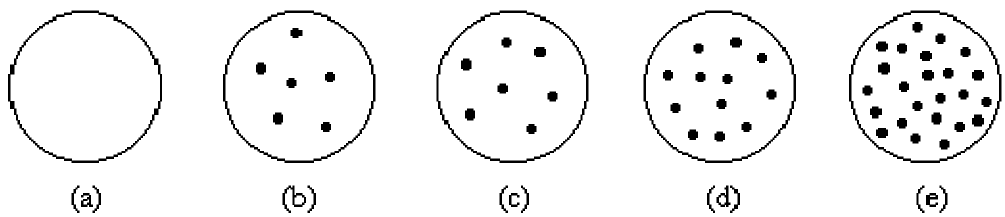


Figure 2

16. 100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C?

a. The water.
b. The alcohol.
c. Both received the same amount of heat.
d. It is impossible to tell from the information given.

17. What is the reason for your answer to question 16?

a. Water has a higher boiling point then the alcohol.
b. Water takes longer to change its temperature than the alcohol.
c. Both increased their temperatures 25°C.
d. Alcohol has a lower density and vapor pressure.
e. Alcohol has a higher specific heat so it heats faster.

18. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

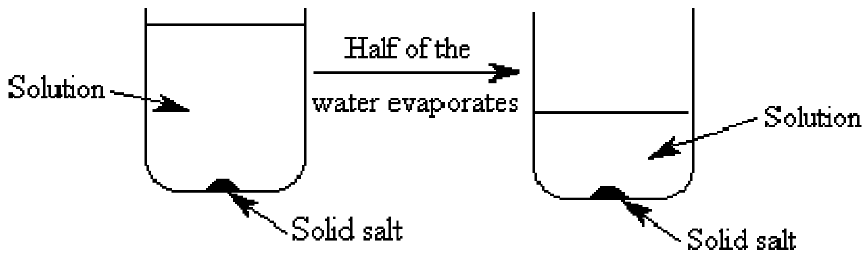
a. less than the nail it came from.
b. the same as the nail it came from.
c. more than the nail it came from.

d. It is impossible to predict.

19. What is the reason for your answer to question 18?

a. Rusting makes the nail lighter.
b. Rust contains iron and oxygen.
c. The nail flakes away.
d. The iron from the nail is destroyed.
e. The flaky rust weighs less than iron.

20. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume temperature remains constant.)



The concentration

a. increases.
b. decreases.
c. stays the same.

21. What is the reason for your answer to question 20?

a. There is the same amount of salt in less water.
b. More solid salt forms.
c. Salt does not evaporate and is left in solution.
d. There is less water.

22. Following is a list of properties of a sample of solid sulfur:

i. Brittle, crystalline solid.
ii. Melting point of 113^{o}C.
iii. Density of 2.1 g/cm3.
iv. Combines with oxygen to form sulfur dioxide

Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample?

a. i and ii only.
b. iii and iv only.
c. iv only.
d. All of these properties would be the same.
e. None of these properties would be the same.

Oklahoma State University
Institutional Review Board
For Human Subject Research

Oklahoma State University Institutional Review Board

Date:	Thursday, March 13, 2008
IRB Application No	AS0821
Proposal Title:	Improving Science Education in the United States
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 3/12/2009

Principal Investigator(s):

Kerry Hammett	John Gelder
1002 E. Virginia Apt. 3	107 PS
Stillwater, OK 74075	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 219 Cordell North (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Shelia Kennison, Chair
Institutional Review Board

VITA

Kerry Michelle Easton Hammett

Candidate for the Degree of

Master of Science

Thesis: Student-Centered Teaching in the Chemistry Classroom

Major Field: Chemistry

Education:

B.S. in Chemistry From Oklahoma State University

Completed the requirements for the Master of Science in Chemistry at Oklahoma State University, Stillwater, Oklahoma in May, 2008.

Name: Kerry M. E. Hammett Date of Degree: May, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: STUDENT-CENTERED TEACHING IN THE CHEMISTRY CLASSROOM

Pages in Study: 183

Candidate for the Degree of Master of Science

Major Field: Chemistry

Findings and Conclusions:

Science education in the United States has become of dire importance amidst the faltering economy and need for national security, yet calls for reform over the last three decades have done little to improve the situation. In the "information age" searching for information has become a trivial task; original thinking, self-motivation, and problem-solving skills have become the highly sought after commodities. In order to prepare for the future, students in the late high school and college years need to develop process skills that allow them to independently ask questions and solve problems. This semester-long study investigates the application of student-centered pedagogical methods to a beginning level chemistry class for elementary education majors. The investigation shows that student-centered methods are effective for learning abstract concepts like chemistry, indicates that type I (field-independent) students perform better in student-centered classes, and describes how students respond to more autonomy in the student-centered classroom.

ADVISER'S APPROVAL: Dr. John Gelder